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## ORIGINAL ARTICLES.

### I.—The Solway Basin and its Permo-Triassic Sequence.

By J. W. Gregory, D.Sc., F.R.S.

THE Solway Firth is the only important ria on the western coast of Scotland; it has a complex history, for denudation and earth-movements of several different dates have contributed to its formation. Uncertainty as to the essential structure of the Solway valley at present renders doubtful its position in the valley system of Southern Scotland. The Solway–Carlisle basin is generally represented as occupying a synclinal between the Lower Palæozoic hills of the Lake District and of the Southern Uplands of Scotland. Thus the sections by E. W. Binney (1865, p. 369, ref. p. 249) and Mr. T. V. Holmes (1889, p. 247, and 1899, pp. 22, 40) represent the valley of the Solway and its eastern continuation as lying along a synclinal and resting on a great thickness of Triassic rocks. The axis of the synclinal is marked by the Lias which occurs to the west of Carlisle. The Solway–Carlisle basin cannot, however, have such a simple synclinal structure, for Carboniferous rocks occur at the surface near the northern shore of the Eastern Solway. This fact is shown by a boring for coal made in 1794 in an old quarry beside the Kirtle Water at Redkirk Mill, 1½ miles to the south-west of Gretna Green. The bore journal was published in Singer's Agricultural Survey of the County of Dumfries, 1812, pp. 670–3; and as that book is scarce and the bore important the record may be conveniently reprinted.

Journal of Boring for Coal at Redkirk, in the Parish of Graitney, 15th May, 1794.

| | yds. | ft. | in. | | yds. | ft. | in. |
|---|---|---|---|---|---|---|---|
| White stone | 4 | 2 | 0 | Strong white stone with water | | | 6 |
| Gray beds | | 1 | 0 | Stone calm | | 1 | 4 |
| White stone | 2 | 0 | 0 | Gray beds | | 2 | 3 |
| White metal partings | | | 6 | Hard brown randed with white | | 2 | 6 |
| Brown stone | 1 | 1 | 6 | Light brown stone | | 2 | 4 |
| Bleas [1] stone | | 2 | 0 | | | | |
| Stone calm [2] | 2 | 0 | 0 | *Carried forward* | 14 | 0 | 11 |

[1] *Blaes* or *blaise* = shale; *bleas* is doubtless a misprint.

[2] 'Calm' is defined by J. Barrowman in *A Glossary of Scotch Mining Terms*, 1886, p. 15, as 'White or light coloured blaes'.

| | yds. | ft. | in. |
|---|---|---|---|
| *Brought forward* | 14 | 0 | 11 |
| White metal[1] partings | | | 5 |
| Brown stone | | 2 | 8 |
| Hard white stone | | | 9 |
| White metal partings | | 1 | 0 |
| Stone calm | 1 | 0 | 8 |
| Stone calm | | 1 | 0 |
| Gray whin with water, large | | 1 | 7 |
| White metal partings | | | 4 |
| Strong white stone | 2 | 1 | 0 |
| White metal partings | | | 6 |
| White stone with water, large | 1 | 0 | 0 |
| White metal partings | | | 2 |
| Soft white stone | | 2 | 10 |
| White metal partings | | | 3 |
| Stone calm | | 1 | 0 |
| White stone | 4 | 0 | 6 |
| Brown metal partings | | 1 | 0 |
| Brown stones | 5 | 0 | 0 |
| Gray beds | | | 4 |
| Gray freestone with water | | 1 | 7 |
| Gray stone with water | 1 | 1 | 2 |
| Brown metal partings | | | 6 |
| Brown stone | 1 | 1 | 0 |
| Strong brown stone | 1 | 2 | 6 |
| Hard blae stone | | 1 | 5 |
| Strong white stone with water | 1 | 1 | 8 |
| Blae stone | 1 | 0 | 7 |
| Hard white stone, thin beds | | 1 | 0 |
| Strong blae stone | 1 | 2 | 10 |
| Soft blae stone | | | 8 |
| Red calm | | 1 | 0 |
| Strong brown stone | 1 | 0 | 7 |
| Strong brown stone | 3 | 0 | 9 |
| Gray stone | | 2 | 10 |
| Brown metal partings | | | 3 |
| Strong brown stone | 2 | 0 | 6 |
| White stone, hard | | 1 | 7 |
| Hard white stone | | | 9 |
| Strong gray randed[2] stone | | 2 | 5 |
| White stone | | | 4 |
| Brown metal partings | | | 4 |
| Brown randed stone with white | | 1 | 3 |
| Strong coal-pipe | | | 1 |
| Brown randed calm | | | 6 |
| Light brown randed stone | 1 | 0 | 6 |
| Light brown randed with white | | 1 | 10 |
| Strong white stone | 1 | 1 | 9 |
| Blaes metal partings | | | 1 |
| White stone | | 1 | 0 |
| Brown stone calm | | 1 | 0 |

| | yds. | ft. | in. |
|---|---|---|---|
| Gray beds | | 2 | 0 |
| Brown stone calm | | | 5 |
| Gray | | 3 | 9 |
| Hard white stone with water | | | 11 |
| Strong gray beds | | 2 | 2 |
| Hard white stone | | 1 | 4 |
| White scap metal | | | 5 |
| Gray beds, strong | | 1 | 6 |
| Strong white stone | | 1 | 0 |
| Strong gray beds | | 1 | 11 |
| Strong gray beds | | 2 | 0 |
| Blue metal partings | | | 6 |
| Strong brown stone | | 1 | 0 |
| Gray beds | | 2 | 0 |
| Hard brown stone | 1 | 1 | 4 |
| Dark brown calm | | 1 | 11 |
| White stone | | | 2 |
| Blue metal | | | 6 |
| Hard blaes stone | 1 | 0 | 0 |
| Blue metal partings | | | 6 |
| Strong white stone | | 2 | 9 |
| Strong white stone, with coal-pipes | 1 | 2 | 9 |
| Strong blaes stone | | | 9 |
| Hard blaes stone | | 1 | 3 |
| Blue metal partings | | | 2 |
| Dark-brown calm stone | | | 7 |
| Dark calm mixed with white | | 2 | 0 |
| Dark bleas stone | | 2 | 0 |
| Strong gray bed | 1 | 0 | 0 |
| Hard white stone | 1 | 1 | 9 |
| Hard gray stone | | 1 | 6 |
| White stone | | 2 | 4 |
| Strong bleas stone | | 2 | 0 |
| Light-red metal | | | 2 |
| Soft blue calm stone | | | 6 |
| White stone mixed with coal-pipes | | 1 | 1 |
| White stone | | | 7 |
| White stone, strong | | 1 | 8 |
| Light-brown stone | | 1 | 11 |
| Light-brown stone | | 2 | 8 |
| Hard brown stone | | 2 | 6 |
| White stone | 1 | 0 | 0 |
| Dark-brown stone calm | 2 | 0 | 6 |
| Hard brown stone | | 2 | 2 |
| Strong gray beds with water | 1 | 0 | 9 |
| Red calm stone | 1 | 0 | 0 |
| Fath. | 45 | 1 | 2 10 |

This succession with its 108 beds in 275 feet, the abundance of white stone, gray whins, "strong gray beds," and layers with coal, indicates that this bore passed from the surface through the Lower

[1] 'Metal' is defined by Barrowman (ibid., p. 44) as 'Hard rock; whin'. In this journal it doubtless meant shale, according to its use in Cumberland and Northumberland (Wright, *English Dialect Dictionary*).

[2] 'Randed' may mean 'striped' or may be a misprint for 'banded'.

Carboniferous Series. The whole succession of the beds in the bore is quite unlike the local Permian or Trias.

This bore journal is not the only evidence for the existence of the Lower Carboniferous beds at this locality; for, as the Busbys remark in an appendix in Singer (1812, p. 673), the grey sandstones may be seen on the bed of the Kirtle Water near the site of the bore. These beds outcrop at the distance of about 450 yards down-stream from the bore and are 250 yards below a footbridge near Old Gretna. They occur at the point represented on the six inch map (Dumfriesshire, Sh. 64 N.W., ed. 1898) beside the 'a' of Kirtle Water, five hundred yards west of Old Gretna. The microscopic character of these sandstones agrees with those of the Lower Carboniferous Series, and they differ from those of the adjacent Triassic beds.

It is clear that Carboniferous rocks occur near the northern shore of the Eastern Solway as well as along the Western Solway. Hence the southern as well as the northern[1] margin of the Annan Sandstone, the Dumfriesshire continuation of the St. Bees Sandstone, rests unconformably on the Carboniferous without any Permian beds intervening.

Whether the Carboniferous rocks of Redkirk are bounded to the south by a fault or pass beneath an unconformable cover of Permian beds is uncertain. The probability appears in favour of their southern margin being faulted. The Solway district is traversed by three series of faults; the dominant faults trend from east to west or from east-north-east to west-south-west; and they are met by two other sets of faults; one set trends from north and south or from north-north-west to south-south-east, and the other set trends from north-west to south-east. The Redkirk bore is close beside the line of continuation of the Boltonfell fault, one of the pair of ridge faults by which, 8 miles to the east of Redkirk, the Lower Carboniferous rocks are upfaulted between the Trias on the south and the Coal-measures at Riddings.

The presence of a raised platform of Carboniferous rocks to the north of the Solway, on which the Bunter Sandstones were deposited directly, shows that whether the Carboniferous beds are cut off to the south by a fault or are covered by the Permians, the Solway basin had been initiated by subsidences and faulting in pre-Bunter times; while it was enlarged by post-Triassic faulting.

The outcrop of Carboniferous rocks at Redkirk is therefore opposed to the synclinal theory of the Solway, according to which, moreover, the St. Bees Sandstone extends under the Solway and continues beneath North-Western Cumberland deep below a thick sheet of gypseous shales. The existence of this extension of the St. Bees Sandstone rests on slender grounds which appear untenable. The evidence of the Redkirk bore has an important bearing on the classification of the Permian and Triassic systems in this district as well as on the structure of the Solway valley. Sir Archibald Geikie, in his preface to the Geological Survey memoir on the neighbourhood of Carlisle, remarked that the classification of the rocks advocated by Mr. T. V. Holmes in the memoir differs from that which was adopted

[1] See Peach & Horne, 1903, pl. iii, sects. 4, 5.

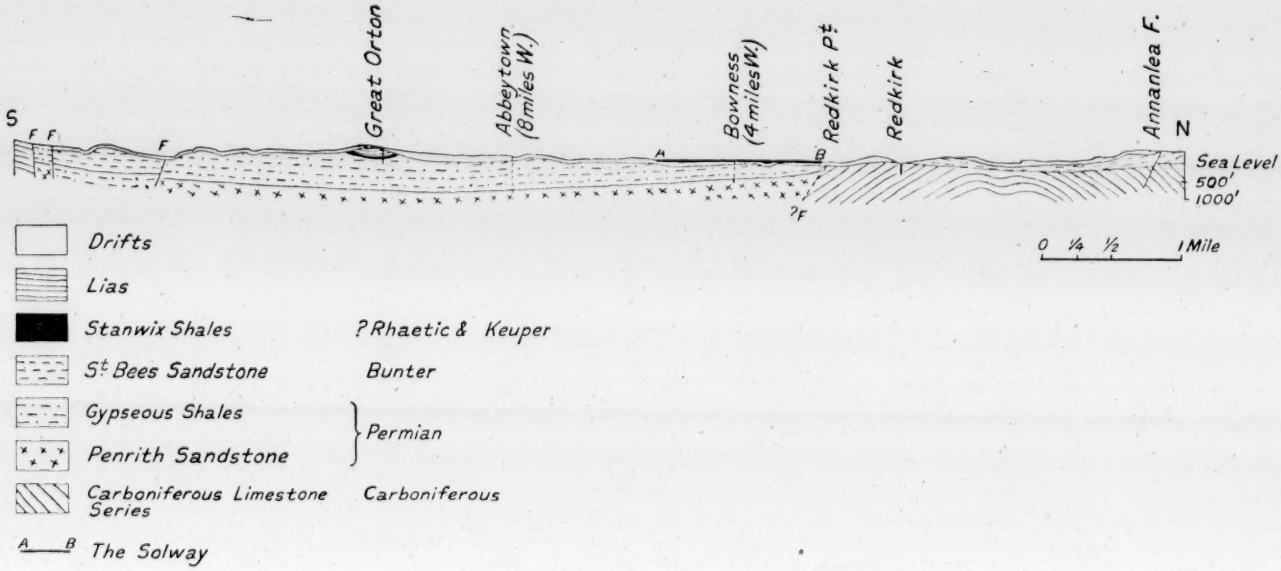


FIG. 1.—Section across the Solway Firth (A–B) and the Carlisle Basin, from the Annanlea Fault in the St. Bees Sandstone of Dumfriesshire to the Carboniferous Series south-west of Carlisle.

by Aveline, Sir Andrew Ramsay, and the Survey maps. Mr. Holmes' classification has been most generally followed.[1] The difference between them may be shown by the following table :—

| Carlisle Memoir and Holmes' paper of 1889. | | Geological Survey Maps. | | Age now generally accepted. |
|---|---|---|---|---|
| Trias | Stanwix Shales | Stanwix Shales (include Upper Gypseous Shales of Holmes) | Keuper | ? Rhætic [2] |
| | Kirklinton Sandstone | Kirklinton Sandstone | | Keuper |
| Permian | Upper Gypseous Shales | — | | — |
| | St. Bees Sandstone | St. Bees Sandstone | Bunter | Bunter |
| | Lower Gypseous Shales | Gypseous Shales | Permian | Permian |
| | Penrith Sandstone | Penrith Sandstone | | |

The essential difference is that according to Mr. Holmes there are three series of shales, viz. the Stanwix Shales above and two lower series containing gypsum; and of these Gypseous Shales he placed one above and the other below the St. Bees Sandstone. The Geological Survey maps recognize only two beds of shales, for they represent the Stanwix Shales as the same horizon as Mr. Holmes' Upper Gypseous Shales. Aveline—in order to avoid an unconformity at the base of the Lias, while accepting the beds at the bottom of the Bowness and Abbeytown bores as the St. Bees Sandstone—identified the Stanwix Marls as the continuation east of Carlisle of the Gypseous Shales of the Great Orton, Bowness, and Abbeytown bores; and against this view Mr. Holmes indignantly and justly protested (1889, pp. 244–7). Etheridge plausibly suggested (in Holmes, 1881, p. 298) that the Stanwix Marls might represent the tea-green marls of the Rhætic; otherwise the Rhætic beds would be absent from this district.

Mr. Holmes admits that only one bed of Gypseous Shales has been seen on the surface; but he holds that the bores at Bowness and Abbeytown revealed the existence of a thick series of Gypseous Shales above the St. Bees Sandstone.

The Bowness bore (Holmes, 1899, pp. 54–5) was sunk in 1809; it passed through 322 feet of Gypseous Shales and left off in a "red stone". No one living appears to have seen this material, which Mr. Holmes has identified as the St. Bees Sandstone. The bore at Abbeytown was put down in 1875–6; it went through 198½ feet of alluvium and glacial deposits; then through 746½ feet of Gypseous Shales; and passed for 75 feet through sandstones which Mr. Holmes has identified as the St. Bees Sandstone (1899, p. 54). As

[1] e.g. by H. B. Woodward, *Geology of England and Wales*, 2nd ed., 1887, p. 212; also J. E. Marr, in *Geology in the Field*, Geol. Assoc. 1910, p. 655.

[2] The Stanwix Shales may include some Upper Keuper as well as the Rhætic, for Holmes (1889, p. 242) claims an unconformity between these beds and the Kirklinton Sandstone.

this identification is responsible for the difficulty in the interpretation of the geology of the Solway–Carlisle basin, its careful reconsideration is justifiable.

If Mr. Holmes' identification of the rock from the Abbeytown and Bowness bores be correct, there would be a double series of Gypseous Shales, one above and one below the St. Bees Sandstone. The existence of the Lower Gypseous Shales is undoubted; they separate the St. Bees Sandstone from the Penrith Sandstone. The Geological Survey maps express some hesitation as to whether this series should be included in the Permian or the Trias, but they show it as certainly situated between the St. Bees and the Penrith Sandstones.

The claim for the existence of the Upper Gypseous Shales rests upon the identification of the sandstone at the bottom of the Bowness and Abbeytown bores as the St. Bees Sandstones. It may appear most unlikely that such an expert in the geology of North-Western Cumberland as Mr. Holmes could be mistaken in this determination; and his view has been further recommended by the improbability of the conclusion offered as the alternative, namely, that the Stanwix Shales are the eastern continuation of the Gypseous Shales of the Great Orton and Bowness bores. Nevertheless, several considerations suggest that the sandstone at the base of the Abbeytown and Bowness bores is really the Penrith Sandstone.

1. Though the two formations are usually easily distinguished, mistakes are possible, as some layers of the St. Bees Sandstone contain redeposited Permian material; most of the sandstone in question was clearly not typical St. Bees Sandstone.

Mr. P. Fleming Smith, the Manager of the Vivian's Boring and Exploration Co., Ltd., the present title of the firm which, as the Cumberland Diamond Boring Co., put down the bore in 1875–6, tells me that the report-book of the bore shows that few cores were obtained from the last 200 or 300 feet and *none from the lowest beds*. The report-book is supported by the testimony of one of the charge men on the staff of the Company who worked at the boring. He states that the lowest bed "of soft sandstone made no core". Hence any identification of the rocks at the bottom of the bore must have been based on fragmentary material.[1] The debris of the St. Bees Sandstone and Penrith Sandstone might easily be mistaken; and under those circumstances the determination of the material at the lower end of the bore as St. Bees Sandstone cannot carry weight against the general stratigraphical evidence.

2. Mr. Holmes was probably predisposed by his classification of the Red Rock Series of Cumberland to regard these sandstones as the St. Bees Sandstone, for he made this identification also for the sandstone of the Bowness bore, of which the only description is "red stone".

[1] In the Carlisle Memoir, issued 1899 (p. 20), the identification of the soft red sandstone as the St. Bees Sandstone is advanced on the examination by Mr. Holmes and his late colleague R. Russell of "the cores showing this lowest bed". As no cores were obtained from that bed if the identification were based on cores, they must have come from some upper part of the boring or from another locality.

3. The rocks at the base of the Abbeytown bore are reported by Mr. Holmes as follows (1899, p. 54) :—

| | Thickness. ft. | in. | Depth. ft. | in. |
|---|---|---|---|---|
| Grey sandstone and blue sandy shale | 24 | 6 | 969 | 6 |
| Soft grey sandstone . . . . | 12 | 6 | 982 | 0 |
| Soft red and white sandstone . . . | 6 | 0 | 988 | 0 |
| Soft red sandstone (left off in) . . | 32 | 0 | 1020 | 0 |

Mr. Fleming Smith has kindly sent me a copy of the journal of the lowest 100 feet of the bore. It is as follows :—

| ft. | in. | ft. | in. | |
|---|---|---|---|---|
| 8 | 0 | 902 | 0 | Red and blue shale, with gypsum and sandstone beds. |
| 11 | 0 | 913 | 0 | Red and grey shale, with gypsum and sandstone beds. |
| 13 | 0 | 926 | 0 | Red and grey shale. |
| 1 | 0 | 927 | 0 | Blue shale. |
| | 6 | 927 | 6 | Grey sandstone. |
| 5 | 0 | 932 | 6 | Red and blue sandy shale. |
| | 6 | 933 | 0 | Dark grey sandstone. |
| 3 | 0 | 936 | 0 | Blue shale. |
| 1 | 6 | 937 | 6 | Grey sandstone. |
| 3 | 6 | 941 | 0 | Red sandy shale. |
| 3 | 0 | 944 | 0 | Blue sandy shale. |
| 1 | 0 | 945 | 0 | Red and grey sandy shale. |
| 15 | 6 | 960 | 6 | Grey grit. |
| 21 | 6 | 982 | 0 | Grey grit (soft ; no core). |
| 6 | 0 | 988 | 0 | Red and white sandstone, soft. |
| 37 | 0 | 1025 | 0 | Red sandstone, soft (no core). |

This description of the lowest beds appears suggestive of the Penrith rather than of the St. Bees Sandstone.[1] The most characteristic feature of the St. Bees Sandstone is that it consists of posts of sandstone separated by layers and partings of shale; the Penrith Sandstone, on the other hand, contains no such shales and usually consists of thick beds of soft sandstone, the colour of which is more variable than that of the St. Bees Sandstone. The lowest 65 feet of the bore was through red, white, and grey sandstone ; this composition and the absence of interbedded shale agree better with the upper part of the Penrith Sandstone than with the St. Bees Sandstone.

4. Mr. Holmes describes the lowest bed of the Abbeytown bore as the ordinary St. Bees Sandstone ; but he lays stress on the correlation of the overlying grey sandstone with that exposed on the bank of the Caldew, 240 yards north of the dyke near Dalston. This position would place that cliff almost up to the fault which in Mr. Holmes' map (1881, pl. xi) separates the St. Bees Sandstone from the Kirklinton Sandstone ; and if the grey sandstone be included in the Kirklinton Sandstone, as Mr. Holmes' map shows to be quite possible, then it would belong to a formation which Mr. Holmes (1899, pp. 6, 31) describes as resembling the Penrith Sandstone and not the St. Bees Sandstone.

[1] The descriptions in the bore journal might conceivably refer to the Upper Coal-measure Sandstones of the Whitehaven type. But even the waste of these measures would be easily distinguished from the Permian and Triassic Sandstones. The lowest beds are probably later than Carboniferous. There is, however, no improbability in the gypseous shales resting unconformably on the Carboniferous in this district.

5. Another improbability involved by the acceptance of the Upper Gypseous Shales is the conclusion that in addition to a minor unconformity between the Stanwix Shales and the Kirklinton Sandstone (Holmes, 1889, p. 242) there is a very marked unconformity at the base of the Lias. Mr. Holmes' section (1899, p. 41) shows the Lias transgressing from the Gypseous Shales over the Kirklinton Sandstone on to the Stanwix Shales. This unconformity is based mainly on a boring made at Great Orton in 1781. According to the record quoted by Mr. Holmes (1899, p. 22) this bore "found a blue stone 3 fathoms from the surface—continued with different stone, mostly bluish till 38 fathoms, then changed to red stone or clay sometimes mixed with veins of white till they came to 60 fathoms". Mr. Holmes interprets this record as showing that the Lias extended from 3 to 38 fathoms, and that the bore then entered the Upper Gypseous Shales and kept in them to the bottom of the bore at 60 fathoms. H. B. Woodward, on the other hand, in a passage in his memoir on the Lias quoted by Mr. Holmes (1899, p. 38), considered that the upper 210 feet of "different stone, mostly bluish" included some Rhætic beds, and this conclusion would appear to be most probable. The recorded "veins of white", instead of being veins of gypsum, the probable explanation, might possibly be based on thin beds of white or grey sandstone; and if so the lower beds might be either Stanwix Shales or Kirklinton Sandstone. But Mr. Holmes' conclusion that the beds containing these white veins are of gypsum is probably correct, as Gypseous Shales may be expected beneath a thin layer of Upper Keuper near Great Orton. The unconformity represented by Mr. Holmes in the Carlisle Memoir at the base of the Lias is possible; but the persistent conformity of the Lower Lias, Rhætic, and Upper Keuper is so widespread throughout Britain, that it requires stronger evidence than the meagre description of the Great Orton bore to establish a strong unconformity between the Lower Lias and the Keuper.

6. The abandonment of the assumed upper series of Gypseous Shales would remove the main difficulty in the interpretation of the Carlisle district, viz. the assumption that west of Carlisle there is above the St. Bees Sandstone a bed of Gypseous Shale which is several hundreds of feet in thickness, and of which there is not a trace along the outcrop of the St. Bees Sandstone, east of Carlisle; although to the south-east of the city there is a thick bed of similar Gypseous Shale, below the St. Bees Sandstone.

7. The Redkirk bore shows that the Permian beds at Bowness should be nearer the surface than was expected when the Annan Sandstones were regarded as the northern part of a sheet of St. Bees Sandstone which extended in a simple synclinal under the whole Solway–Carlisle basin.

The Redkirk bore further shows that the St. Bees Sandstone north of the Solway rests unconformably on the Carboniferous; and south of the Solway, to the west of Carlisle, the most northern certain extension of the St. Bees Sandstone is in the band which passes 3 miles south of Carlisle, and continues through Dalston and Wigton to the coast at Allonby Bay. This band probably lies in a trough fault.

There is no evidence apart from the identification from the two bores of the presence of St. Bees Sandstone in Cumberland anywhere to the north of that band; and the probabilities seem to me in favour of its absence. On the north of the Solway the St. Bees Sandstone extends as far west as Annan; but the Redkirk bore shows that the only known beds on the southern side of that area of St. Bees Sandstone are Lower Carboniferous Sandstone. There is no trace of the St. Bees Sandstone to the west of Annan; the rocks of the Penrith Sandstone group reach the northern shore of the Solway at Caerlave rock; and south of the coast of Dumfries in this area a band of Carboniferous rocks, covered by sea and drifts, probably connects the Carboniferous outcrop at Arbigland with that of Ruthwell. These Carboniferous rocks may be covered to the south by Penrith Sandstone or by the Gypseous Shales, and the natural rock to find beneath the Gypseous Shales at Bowness and Abbeytown is the Penrith Sandstone.

As the St. Bees Sandstone does not occur north of the Solway further west than Annan, there is no improbability in that formation not extending as far west as Bowness or Abbeytown on the southern side. The assumption of a sheet of St. Bees Sandstone under North-Western Cumberland, north of the Wigton–Allonby outcrop, appears to me improbable.

### *Summary of Conclusions.*

The occurrence, as shown by the Redkirk bore, of the Carboniferous rocks near the surface on the northern shore of the eastern Solway, and the identification of the red rocks at the bottom of the Abbeytown bore as Penrith Sandstone, render unnecessary either the assumption of the existence of the Upper Gypseous Shales or the view that the Stanwix Shales are the continuation of the Gypseous Shales of the Abbeytown and Bowness bores. Thereby is removed the chief difficulty in the interpretation of the geology of North-Western Cumberland and the Solway Firth.

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## II.—The Petrology of the Suffolk Box-stones (Crag).

By P. G. H. Boswell, D.I.C., B.Sc.

(PLATE X.)

ALTHOUGH much has been written upon the palæontology of the Suffolk box-stones, no description appears hitherto to have been published of the petrology of these boulders. This is the more curious on account of the light it might throw upon the disputed question of their source, no similar sandstone having yet been recognized with certainty in situ.[1] The most recent account of the molluscan fauna is by my friend Mr. Alfred Bell. In a preliminary paper[2] he has given a list of sixty-three species (excluding cetacean bones, teeth, crustaceans, etc.), about twelve new species and varieties being described. Mr. Bell has now kindly let me see in advance the MS. of a revised list of Mollusca (seventy-six species), much new box-stone material having been obtained in the last few years. As a result of recent work, he considers the affinities of the fauna to be rather with the Rupelian (Continental Oligocene) than with the Bolderian or Diestian, as he formerly thought. Mr. Clement Reid, in *The Pliocene Deposits of Britain* (Mem. Geol. Survey, 1890), considered the box-stones to be of about the same age as the Diestian Beds, but Mr. F. W. Harmer has, in later publications, been inclined to consider them to be rather older and of very early Pliocene age.

The box-stones are masses of a fairly hard brown sandstone, about the size of the fist, or a little larger. These boulders are often well rolled, but sometimes occur as flattened tabular lumps, and have received their name from workmen owing to the fact that about 10 per cent of them, on being broken open, are found to have enclosed fossil remains. Fragments of wood and bone, as well as teeth and casts of Mollusca, occur in this way, and, while it appears to be probable that some of the box-stones may have been formed by concretionary segregation of iron-oxides and calcium phosphate and carbonate around organic nuclei, others appear merely to be the broken-up fragments of a ferruginous sandstone. The latter may have been derived from iron-impregnated bands in the original sandy beds like those met with in the Lower Greensand or Red Crag.

Large muscovite flakes glisten here and there, but macroscopically the sandstone cannot be said to be highly micaceous, nor very compact. Casts and impressions of shells are sometimes seen, and more rarely a fragment of a calcite shell, e.g. *Pecten*. As in the Coralline and Red Crags when they are decalcified, the aragonite shells have usually disappeared as a result of solution.

*Appearance in thin section.*—A number of box-stones from Foxhall, Sutton, Waldringfield, the mouth of the Deben, and also from the collection of the Imperial College of Science and Technology have been sliced and examined. The numbers in square brackets, attached

[1] Lyell drew attention to the similarity between the box-stones and some Antwerp beds near Berchem (Q.J.G.S., vol. xxvi, p. 513, 1870). Other authors have noted their similarity to the Diestian.

[2] "On the Zones of the East Anglian Crags": Journ. Ipswich and District Field Club, vol. iii, p. 5, 1911.

to descriptions, etc., refer to the slides and accompanying mineral separations in the collection preserved at the College.

Under the microscope the rock is seen to be a coarse sandstone made up largely of grains of clear quartz set in a brown matrix, often so dark in colour as to appear isotropic, but occasionally showing aggregate polarization. There is little uniformity in the size of the grains, the smaller helping to fill up the interstices between the larger, but occasionally there are patches of the brown cement, free from grains, as big as the largest of the latter (Fig. 1). The average

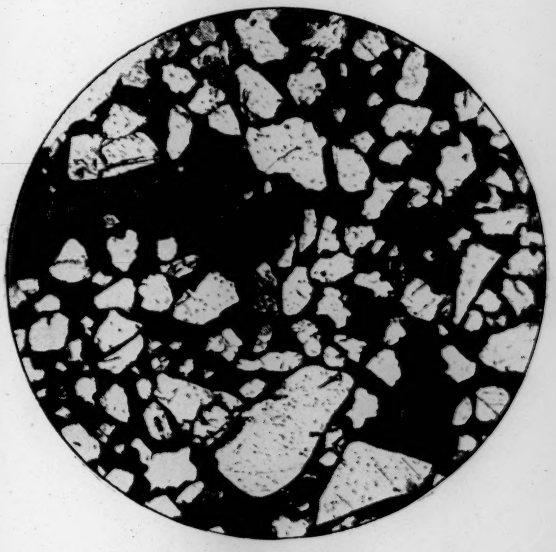

FIG. 1.—Box-stone, Pettistree Hall, Sutton [204], showing large angular quartz-grains and a high proportion of phosphatic matrix.

diameter of the fragments is about ·3 mm., the smallest being about ·12 mm., and the largest up to ·5 mm., or even 1 mm., diameter. There is very little material above the last size. The larger grains of quartz are somewhat rounded, and those of felspar almost square, but the smaller grains are subangular to angular, the tendency to rounding diminishing with the size. Some of the smaller grains are astonishingly sharp and angular, most being rather triangular, but a few being of long and irregular, quadrilateral form. Usually there is an entire absence of any grading in size. A specimen from Sutton [206] differs in containing smaller grains, averaging ·16 mm. diameter, set more closely together, with much less matrix (Fig. 2).

The quartz is usually very clear and colourless, and free from enclosures. In a few cases, however, parallel rows occur of very small inclusions, like those met with in quartz from granites and gneisses, and rarely mineral inclusions (zircon, etc., but no sillimanite) have been seen. Some grains are coated with limonitic dust, and

occasionally there is a thin border of subsequently deposited quartz separated from the original grain by a very thin pellicle of brown material. Cracks sometimes occur and are stained brown. Undulose extinction (strain-shadows), characteristic of quartz from crystalline rocks which have undergone dynamic metamorphism, has been observed, but is not common; one compound grain of quartzite set in the brown matrix was made up of three or four closely locking grains of quartz, one of which showed strain-shadows.

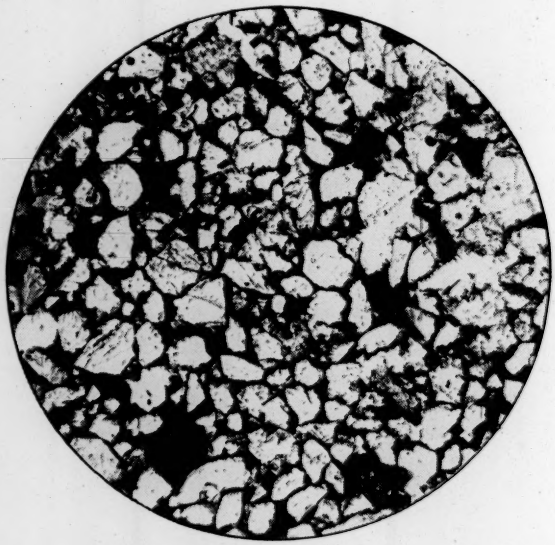

FIG. 2.—Box-stone, Sutton. [206.] Extreme variety with very little cement.

In thin sections little felspar is to be seen, the proportion of the grains of felspar to quartz being about one to fifty. Some of the larger grains are almost square, and the mineral is generally full of alteration products; twinning is usually not seen.

As a general rule, casts only of the Mollusca are found in box-stones, so that it is interesting to meet occasionally cross-sections of shell-fragments, apparently of bivalves. These sections are long, and somewhat lenticular, having a strong brown-stained border, and an interior made up of an aggregate of small yellow-stained recrystallized calcite grains.

The deep colour of the matrix seems to mask effectually the heavier minerals which are found on crushing and separating (see pp. 254–7). Certain patches exhibiting aggregate polarization occur here and there, but are too deeply stained to be determinable. Ovoid and circular dark-brown isotropic pellets, probably representing some organic remains, are occasionally seen, but no structure can be made out in them, and the round empty hollows sometimes found may be due to their removal.

The brown matrix is often present in considerable amount, measurements of relative volumes of sand-grains and cement-filled interspaces being for extreme values—sand 19·8 per cent, matrix 80·2 per cent, and sand 80·1 per cent, matrix 19·9 per cent. (These values were calculated from the areal distribution in thin sections, e.g. Figs. 1 and 2.) An analysis of material from the mouth of the Deben [203] gave the following proportions by weight: sand 57·43 per cent, matrix 42 57 per cent, from which the proportions by volume, sand 62 per cent, and matrix 38 per cent, can be calculated roughly on the assumption that the sand is quartz and the matrix calcium phosphate.

The cement sometimes exhibits concentric banding due to growth round the quartz-grains. On treatment with dilute acid a large proportion of phosphate is found,[1] and an analysis of the rock kindly carried out by my colleague, Mr. G. E. Kirby, A.R.C.Sc., B.Sc., shows 20·1 per cent of calcium phosphate, 6·5 per cent of calcium carbonate, and 0·84 per cent of soluble silica.

This percentage of phosphate is far too great to be accounted for by the little detrital apatite present, hence it probably exists in the cement as limonite-stained phosphorite. Glauconite may also have played a part in cementation, but it has not been detected as such. Surprisingly few grains of this mineral occur in the residues. Limonite itself undoubtedly acts as a cement, and prolonged boiling with acid is required to clean the crushed sandstone. Cementation has also been effected by the deposition of secondary silica, partly as quartz and partly in an opaline form. The latter appears to be soluble in acid, and is found on analysis of the matrix; the finding of opal also among the detrital mineral grains suggests that some of the apparently isotropic pellets and matrix may be this form of silica obscured by iron-staining. Other pellets may be iron-stained calcareous material. Marked effervescence with cold dilute acids indicates that calcium carbonate also is present as cement.

*Mineral constitution.*—The sandstones, being fairly hard, were crushed in a steel mortar, and, after sifting to 1 mm. the compound grains were removed. The material was subjected to prolonged boiling with dilute hydrochloric acid to remove the matrix from the grains. A clean, white, micaceous sand was obtained, but it is noteworthy that the muscovite is not strikingly apparent in the untreated box-stones. The sand was then treated with either bromoform or Sonstadt solution (mercuric potassium iodide), and crops obtained of density $< 2{\cdot}59$, which contained potash felspars, opal, etc., between 2·59 and 2·8, which contained quartz and plagioclase felspars, and $> 2{\cdot}8$. The last crop was then farther separated by electro-magnetic action (after minerals such as magnetite had been removed by means of a bar-magnet), and the non-magnetic portion treated with methylene iodide (density 3·33). The crop of density between 3·33 and 2·8 contained andalusite, apatite, mica, etc. Mineral grains were mounted temporarily in clove oil (R.I. 1·534), as being very similar in refractive index to Canada balsam, and in other oils of known and differing refractive indices, for examination

[1] There is sufficient in the rock for a fragment to yield the ordinary blowpipe reactions for a phosphate.

under the microscope in transmitted and reflected light. Individual mineral species were isolated by hand-picking under a lens (× 20 diameters) in which work a background of black paper was found to be advantageous. Besides the well-known opaque minerals, certain others can be recognized by their characteristic appearance in reflected light, and can be picked out with ease. Muscovite is easily separated by rolling the residue down a rough sheet of paper. Kyanite is clear and glassy, and usually more or less rectangular in form. Andalusite is whitish or dirty-white in appearance, the grains being more irregular. Garnet is pink to colourless, and its fracture causes the mineral to have a well-marked sugary look. Staurolite occurs as deep golden grains, sometimes brownish, but not so metallic-looking as rutile, and epidote as pretty lemon-yellow to yellow-green grains, both minerals being present as irregular fragments. Rutile has a characteristic reddish-brown metallic appearance, and is often prismatic. Green hornblende is easily recognized and isolated. Tourmaline has a smoky, bottle-green to brown tint, and frequently the larger grains have a hummocky shape.

The following is a brief account of the more important minerals:—

*Magnetite* is fairly abundant, either as angular fragments or in well-rounded grains about ·13 mm. in diameter. A few crystals with octahedron faces have been noted.

*Garnet* is an abundant and characteristic mineral, being usually pale pink, but occasionally reddish or colourless. In nearly every case the grains (·2 to ·4 mm. diameter) are very irregular and of all shapes, showing sub-conchoidal fracture and re-entrant angles, but a few occur as platy fragments due to the imperfect (110) cleavage. Rounded grains, if they occur, are rare, and all appear to be entirely isotropic. Inclusions, apparently glassy, occur as well-shaped dodecahedral negative crystals. (Pl. X, Fig. 1.)

*Zircon* is not so abundant as usual in sediments, in which it is ubiquitous. Small crystals less than ·12 mm. long are not common, the average size of the abraded prismatic grains being ·13 × ·03 mm. Good crystal form and angles are rarely seen.

*Rutile* is fairly plentiful, rounded prismatic grains of red-brown tint being common. The yellow variety is rarer, and well-formed crystals are scarce. The grains are larger and more numerous than those of its constant associate in sediments, zircon.

*Ilmenite* occurs in profusion, constituting a large part of the first electromagnetic crop. The fragments are usually small and rather angular (·13 mm. diameter), but a few are rounded. They are often surrounded by a comparatively clear border of leucoxene, showing aggregate polarization. By reflected light the mineral has a bright black lustre, and is sometimes striated, but grains are often coated, in part or entirely, with the whitish alteration product, leucoxene.

*Tourmaline.*—This mineral is usually of the kind varying from a greyish- to yellow-brown. A very pretty reddish-purple form also occurs. Rounded and broken grains, averaging ·18 mm. diameter, are common, but well-formed prismatic crystals are smaller and rarer; these sometimes exhibit hemimorphism, the prisms being terminated by rhombohedra.

*Calcite* occurs as grains recrystallized from shell-fragments, but has mostly been removed by solution.

*Apatite* is of rare occurrence, probably having been in part removed by solution. It is present as rounded grains which are almost isotropic, and yield a uniaxial figure, being optically negative. Such grains are caused by the imperfect (0001) cleavage. It also occurs in tiny well-formed prisms (·1 × ·025 mm.) often terminated by pyramids. These crystals have a clear, limpid appearance, fairly high refractive index, straight extinction, and very low birefringence.

*Quartz* is the most abundant constituent of the sandstone, the larger grains being moderately rounded, and the smaller, angular. The only inclusions observed have been parallel rows of tiny bubbles, which appear to be glassy and isotropic. The average dimensions are given on p. 251.

*Andalusite* is abundant in the box-stones and is characteristic of the assemblage. A quantity of it (Pl. X, Fig. 2) was isolated from the non-magnetic portion of the residue of density $> 2{\cdot}83$ and $< 3{\cdot}33$ by hand-picking, and the identification confirmed. The usual size of the grains is ·18 to ·35 mm. diameter, and most contain abundant dark, opaque, rounded inclusions. The grains are bounded by the good cleavage parallel to (110), and a few show pleochroism in a salmon-pink tint for light vibrating parallel to the X-axis, in the direction of which the grains are often elongated. The grains show straight extinction, low polarization colours, and a curved brush in convergent polarized light.

*Staurolite* is a characteristic and dominant mineral. It occurs as irregular grains, averaging ·23 mm. in diameter, varying in colour from a pale gold to yellow-brown. The fracture is very irregular, some fraying being seen at the edges, and the pleochroism, in tints of golden-yellow, is very marked. Inclusions are abundant, and appear to be glassy and of varied form. (Pl. X, Fig. 4.)

*Topaz* is rare, and is found as platy colourless grains not unlike mica, determined by the basal cleavage. The refractive index is, however, higher, the optical sign is positive, and the optic axial angle is greater. Topaz is met with in the non-magnetic portion of the residue of density $> 3{\cdot}3$.

*Marcasite* is not abundant and may be an authigenic constituent. It occurs in small ragged grains, with a yellowish-white metallic lustre by reflected light, but is partly altered to brown limonite.

*Actinolite.*—A number of fibrous, colourless elongated grains, with an extinction angle up to 8°, have been referred to this mineral.

*Hornblende*, green and pleochroic, with a low extinction angle, occurs frequently as grains determined by the perfect (110) cleavage.

*Epidote* is fairly abundant, occurring in yellow-green grains (averaging ·2 mm. diameter) which can be hand-picked by reflected light. It is found in the middle magnetic crop with staurolite and tourmaline. The grains are sometimes tabular on account of the basal cleavage, and somewhat rectangular, the imperfect cleavage parallel to (100) being occasionally seen. Many of the irregular grains are pleochroic in yellow-green tints, and show, in convergent light, the emergence of an optic axis. (Pl. X, Fig. 3.)

*Muscovite* is very plentiful in the heavy residues and is present as large flakes, most being rounded, ·5 mm. in diameter and ·02 mm. in thickness. On account of the large surface area and consequent slow settlement in heavy liquids, much muscovite remains with the light crop of density < 2·8.

*Sphene* (?).—Some irregular coffee-brown grains of high refractive index are doubtfully referred to this mineral.

*Orthoclase* is fairly plentiful, but is much less abundant than plagioclase. The crystal fragments are often roughly rectangular and are generally much kaolinized.

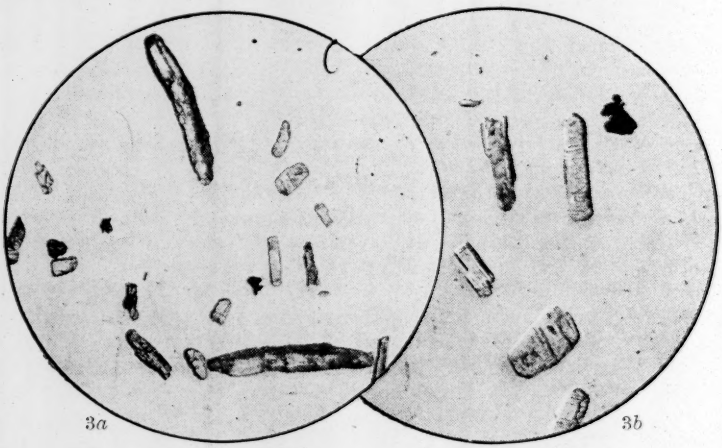


FIG. 3.—Kyanite grains from box-stone, Sutton. [206.] (*a*) Large bent grains. (*b*) Some of the smaller grains in Fig. 3*a*.

*Microcline* is not abundant, but grains have been observed with albite-twinning (symmetrical extinction angle 16°) and refractive index below 1·525.

*Kyanite* is abundant, but in some samples a little less so than andalusite. Many of the grains are of considerable size, and a few of the largest are bent in a remarkable manner. Most of the grains are tabular, lying upon the perfect cleavage faces parallel to (100). The (010) cleavage produces long grains, and the basal parting results in approximate rectangularity and cross-cracks. Pleochroism, in ultramarine blue, is very rare, but examples have been seen with a beautiful colour. The trace of the optic axial plane lies at about 31° to the edge (010) ∧ (100), and plates lying on (100) give an emergence of the acute bisectrix. A few grains resting upon the (010) face have been observed, and these give straight extinction and no figure in convergent light. The average size of the crystals is ·44 mm., but some large crystals are as much as 1·7 mm. in length. The latter are sometimes bent in a curious way, and from their extinction it is concluded that the irregularity is due to crystallization along the bent foliation planes of metamorphic rocks. (Text-figs. 3*a*, *b*.)

*Plagioclase* is fairly plentiful, and from its specific gravity and mean refractive index appears mostly to be oligoclase-andesine, but rarely a few grains occur of refractive index greater than 1·560. These are probably labradorite.

*Glauconite.*—A very few grains only of this mineral have been observed in a large number of samples examined, and the rarity of its occurrence is in sharp contrast to its abundance in the Diestian of Belgium and Coralline Crag of East Anglia. It may be, as in the case of the Antwerp Crag and the Red Crag of Suffolk, etc., that decomposition of the glauconite has taken place, resulting in the production of the limonite and secondary silica which are so abundant in the rock. There is no justification for applying the term 'glauconitic sandstone' to the box-stones, as several authors have done. Nevertheless, the association of phosphatic minerals and glauconite is to be expected on genetic grounds.[1]

*Limonite* is very abundant, giving the sandstone its brown or yellow colour. It coats quartz grains and impregnates the matrix, probably occurring as a cement. Grains which appear by reflected light to be limonite, but which occur in the middle-magnetic crops (limonite is truly non-magnetic) are no doubt actually magnetite, glauconite, or other iron-bearing minerals which have undergone surface decomposition.

*Opal.*—A mineral which often coats other grains (magnetite, etc.) and occurs also in the sand of density below 2·59 is seen to be clear or pale brownish by transmitted light, but white and milky by reflected light. Its refractive index is below that of Canada balsam (1·532), and it appears to be isotropic, so has been referred to opal. It probably acts in part as a cement.

It is evident from the foregoing list that the box-stones have a peculiarly rich and characteristic mineral assemblage. On comparing the list with the assemblages of other deposits, particularly, perhaps, the various divisions of the East Anglian Tertiaries, we can say that the Box-stone Bed is characterized by the large size of its detrital grains, and its richness, both as regards variety and occurrence, in heavy minerals. The typical minerals are red garnet, andalusite, staurolite, epidote, muscovite, and kyanite, with, less importantly, green amphiboles, brown tourmaline, etc. Rutile and zircon appear to be ubiquitous in deposits of all ages, but are really less abundant than usual (especially zircon) in the box-stones. It is rather surprising not to meet with more biotite, particularly as this mineral occurs, though not abundantly, in the Thanet Beds and London Clay in East Anglia, and is plentiful in the later Crag deposits. Opal, limonite, phosphorite, and glauconite are probably authigenic, and marcasite and some of the leucoxene may be also of subsequent formation.

The mineral assemblage detailed above indicates very clearly that the source of the box-stones is to be looked for in an area adjacent to a massif of crystalline rocks which have undergone regional metamorphism, and bear quartz with strain-shadows, felspars, and such minerals of metamorphic origin as tourmaline, andalusite,

[1] J. J. H. Teall, Proc. Geol. Assoc., vol. xvi, p. 383, 1900.

staurolite, epidote, muscovite, and kyanite, in great abundance. The richness of the mineral suite and the angularity and large size of the grains, with the absence of grading in size, suggests that the constituents had not travelled far. The extraordinary profusion of andalusite and muscovite is noteworthy, but it is not clear why biotite should be as rare as it is, when epidote and other ferromagnesian minerals are plentiful and fresh.

The nearest area which would yield the detrital minerals described is undoubtedly the region of the Ardennes, the metamorphic rocks of which have been described in detail in so many publications of the Belgian geological societies. In this connexion the mineral constitution of the Tertiary deposits of Belgium and Northern France is interesting. A discussion of these, and a comparison of the minerals of the Box-stone Bed with those of the East Anglian Eocene, Pliocene, and Glacial beds, must be reserved for a future paper.

A comparison of the petrology of the box-stones with that of British Pliocene deposits generally is also interesting. In mineral constitution the box-stones have no counterpart, so far as the writer's examination of sediments goes. The Lenham Beds (as well as other high-level ferruginous sandstones of the North Downs), which have been said to possess a molluscan fauna similar to that of the box-stones, show interesting petrological differences. Writing in 1870 on the box-stones, Sir E. Ray Lankester gave it as his opinion that they were very probably of the same age as the Lenham Sandstone, which they resembled most closely in condition and contents.[1] In the light of more recent work the statements require modification. The fauna is an older one, and the beds differ petrologically. The material of the Lenham Beds is finer, less angular, and is well graded. There seems to be no phosphatic cement. The mineral assemblage is less rich than that of the box-stones, and garnets, if present, are rare. (The same remarks apply to the Netley Heath sand.) While the box-stones and Lenham Beds may have been derived from the same area, the former certainly did not arise from the denudation of the latter. Neither is there any striking resemblance between the box-stones and such Diestian material as the writer has been able to obtain from the Continent, although the mineral composition of the latter beds is similar but less rich. More work remains to be done upon the Continental Tertiary deposits.

The mineral suite of the box-stones conforms generally to that of the East Anglian Pliocene deposits, and is entirely different from the assemblage found in the Eocene beds. It is highly improbable that the same tract of country and area of rocks yielded the material of both series of sediments. The break in mineral composition between the London Clay or the latest Eocene deposits in East Anglia, the Bagshot Beds, and the box-stones, is as striking and significant as the palæontological gap.

My thanks are due to my friends Mr. Alfred Bell and Mr. S. A. Notcutt, of Ipswich, for providing me with some of the box-stone material examined.

[1] "Contributions to a knowledge of the Newer Tertiaries of Suffolk and their Fauna": Q.J.G.S., vol. xxvi, p. 501, 1870.

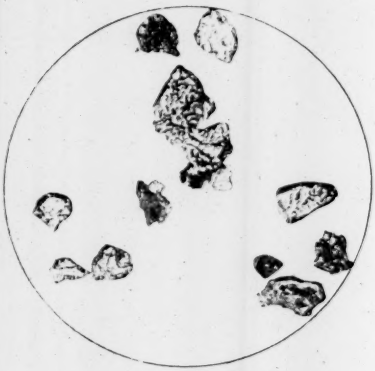

Fig. 1.

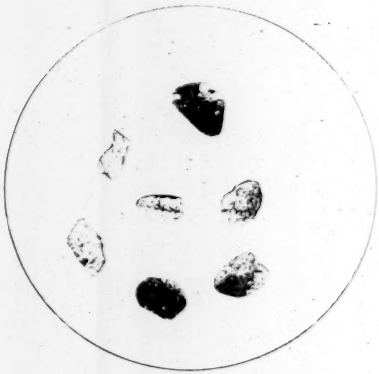

Fig. 2.

Fig. 3.

Fig. 4.

Microphotographs of Grains of Heavy DETRITAL MINERALS from the Suffolk Box-stones.

PLATE X.

MICROPHOTOGRAPHS OF GRAINS OF HEAVY DETRITAL MINERALS FROM THE SUFFOLK BOX-STONES.

FIG. 1. Angular grains of pink garnet. Mouth of R. Deben. [203.] See p. 254.
,, 2. Andalusite, Sutton [206], many grains dusky with inclusions. See p. 255.
,, 3. Epidote, Sutton. [206.] The darker grains in the photograph are those giving the strong yellow-green tint due to pleochroism. See p. 255.
,, 4. Staurolite, Foxhall. [202.] Irregular angular grains, a few showing frayed edges. See p. 255.

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## III.—STUDIES IN EDRIOASTEROIDEA, VII. MORPHOLOGY AND BIONOMICS OF THE EDRIOASTERIDAE.[1]

By F. A. BATHER, M.A., D.Sc., F.R.S.

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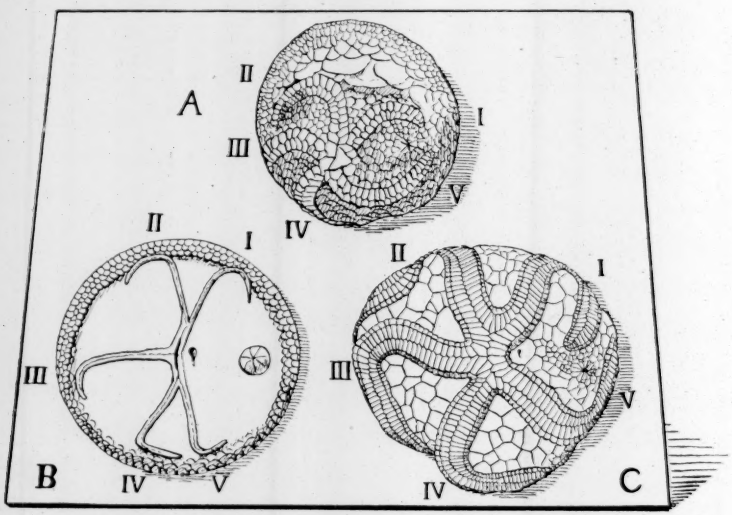
THE facts concerning the Curvature of the Subvective Grooves have been summarized in Study IV (1914, p. 122). They show that no distinction can be drawn in this respect between Edrioasteroidea and Cystidea Diploporita, as some have pretended.

The facts of individual growth, as inferred from a comparison of large and small specimens of the same species, indicate that the rays increased in relative length with age, and thus wound more and more along the periphery. It may further be inferred, from tracing the course of each ray, that the initiation of the curve was due simply to the primitively straight course of the ray being turned aside by the peripheral limit. It follows from this that the right-handedness or left-handedness of the coil was not a feature of the young, and that the one is not a mere reversal or mirror-image of the other. The distinction, however, being characteristic of species separated by other characters, cannot be fortuitous. There must have been some structure or habit in each species predisposing a turn of the coil in a solar or contrasolar direction. It is clear that the cause cannot have been, as Jaekel seems to suggest (1899, p. 24), a torsion of the circumoral region, for in that event the proximal and distal curvatures of a single groove would never be opposed, as they so often are, and that not only in the right posterior ray.

If the difference of coil were due to such a fundamental change in the constitution of the animal as would produce a mirror-image, then the change would be accompanied by a change in the coil of the gut from solar to contrasolar or *vice versa*. This, however, does not seem to have been the case, for such evidence as we have as to the position of the rectum indicates a solar coil (as viewed from the oral pole) whether the grooves were solar as in *E. buchianus* (Study II, 1900, p. 199) or contrasolar as in *E. bigsbyi* (Study IV, 1914, p. 167). Jaekel's conclusion that the gut of the Edrioasteroidea had the normal solar coil of Echinoderma is probably correct, though his main argument, drawn from the supposed constant contrasolar curve of the rays, rests on an incorrect premiss.

[1] Continued from p. 215.

A contrasolar curve of the rays, though not constant, is certainly prevalent in the Edrioasteroidea as a whole, and is regarded by Dr. A. F. Foerste (1914) "as the primitive condition among species with curved rays". Any explanation must, however, take into account the fact that it is so generally accompanied by a solar curve of the right posterior ray (V). To explain the latter feature, Dr. Foerste has put forward some plausible speculations, which if provided with a more extensive foundation of observed facts, might go far to solve the whole problem.




TEXT-FIGURE 1.—Diagrams to show the effect of a sloping position on the course of the rays.

A. A specimen of *Agelacrinus pileus*, traced from a photograph published by A. F. Foerste, 1914, op. cit., pl. ii, fig. 1. × 2 diam.

B. A diagram showing the effect of gravity on rays still marked by triradiate symmetry.

C. *Edrioaster bigsbyi* placed in the same position as A and B. Nat. size.

From observations mainly on *Agelacrinus pileus*, Dr. Foerste shows that the theca is frequently sagged to one side, and from this he infers the direction of slope of the surface (e.g. a valve of the brachiopod *Rafinesquina*) to which the Edrioasteroid was attached. If his argument be correct, then it appears that the right interradius (V IV) was generally directed upwards, so that the anus was to the right of the mouth. Assuming, as is natural, that the slope of the brachiopod valve was toward the direction of the prevailing currents, then the anal stream would be swept away without passing over either the mouth or any considerable part of the food-grooves; moreover the greatest width of the peristome would be in the line of the current. So far, then, the interpretation of the facts is consistent with a healthy pelmatozoic mode of life. (Text-fig. 1, A.)

Dr. Foerste applies this probable position of the living animal to account for the reversed, i.e. solar, curve of the right posterior ray (V). Speaking of an Agelacrinid with its fixed border of small plates, he writes (p. 404): "the position . . . would tend to increase the tension along the upper part of the margin and just within the adjacent part of the peripheral ring. If, at the same time, the anus were dragged slightly downward and toward the left, the proximal part of the right ray (No. 4) being directed up the supporting slope, then the greatest tension would be on the upper, right-hand side of the inner curve of the peripheral ring, possibly sufficiently below the distal part of the right posterior ray (No. 5), in young specimens, to loosen the contact between this part of the peripheral ring and the immediately adjacent part of the posterior or anal interambulacral area, and thus to admit of the curvature of the right posterior ray in a solar, rather than a contrasolar direction." He finds support for this view in the frequent presence of small plates "along the upper margin of the anal pyramid", the animal being oriented as above described. However that may be, the presence of such small plates on the solar side of the anus (as already recorded in *Edrioaster bigsbyi*, 1914, Pl. X, Fig. 9), certainly indicates the presence of the underlying rectum, and thus confirms the view that the gut had a solar coil.

Dr. Foerste's argument has been given in his own words because it is not easy to follow. If, however, he is correct as to the normal position of the living animal, then we might find herein a very simple explanation not merely of the solar curve of ray V, but of the contrasolar curve of all the other rays. If the animal be laid on a slope with the anus to the right of the mouth, then its various parts are all subject to a gravitational force pulling down the slope (text-fig. 1, B). The grooves, with their cover-plates, their heavy floor-plates, and the various systems of organs associated therewith, are heavier, i.e. subject to a stronger pull, than are the intervening thinly plated areas. Consequently, when the grooves have grown out so far that they have to turn one way or the other, they will naturally turn in the direction of this pull. In other words, grooves IV, III, and II will acquire a contrasolar bend, and groove V a solar bend. Groove I should, on this hypothesis, most naturally have a solar bend; but owing to the greater width of the posterior interradius and the primitive triradiate plan of branching, the proximal position of this groove may very well have been directed almost straight down the slope, so that the action of gravity would be indifferent, and its course might rather be determined by the encroachment of groove II. The strong re-curvature of groove V is further aided by gravity acting on the rectum; but in forms that had structures such as ampullae on the inner side of the floor-plates, the posterior mesentery would have opposed an effective bar to the passage of the groove across it.

This hypothesis is suggested by facts observed in undoubtedly sessile forms, and if it is to be applied to the Edrioasteridae, we must suppose that they also assumed a similar sloping habit. Here, as in so many similar cases, the field collector and observers have not supplied the laboratory worker with the desired evidence. The section across a specimen of *Edrioaster bigsbyi* (1914, Plate X, Fig. 10) shows that,

in that individual at least, the right side was higher than the left. Let us, at any rate, test the hypothesis by applying it to the truly remarkable disposition of the grooves in that specimen (text-fig. 1, c). No sooner do we place the specimen on a slope, with the proximal region of ray IV directed upwards, than all the hitherto inexplicable curves appear the most obvious result of the downward pull. That peculiar inward bend of ray IV is a simple downward sag where its course is at right angles to the pull. The initial solar curves of rays III and IV, and the initial contrasolar curve of ray V, are similar sags, and contrast with the greater straightness of the corresponding region in rays I and II. Contrast again the sharp flexure of ray III, with the more rounded curve of ray II, and the still more open curve of ray I. At all points we see the action of the same force ; a force which may be slight but which is always at work. Now at last we appreciate the true meaning of what was previously styled the "peculiar aspect of independent life" given to these rays by their varying curves. There is here a struggle between two forces: the internal tendency of the grooves to grow straight outwards from the mouth at equal distances from one another, and the external pull of gravity, acting equally on all the grooves, but affecting each in a different way according to its position. Thus arises that unlikeness in likeness which gives the fossil its peculiar beauty.

If there be any truth in this explanation, it will of course be necessary to suppose that other species, with rays otherwise disposed, lived in a different position. In *Agelacrinus hamiltonensis*, for instance, ray IV must have lain more to the right, and so have come under the pull of gravity on that side with the result that rays I, II, III have a contrasolar bend, and rays IV and V a solar bend. In that species, with no internal ampullae, groove V has come right round the anus. It is not quite so easy to explain those forms in which all the grooves are either solar or contrasolar, but in the former it is worth noting that ray V is not strongly bent in towards the anus (see *E. buchianus*, 1900, Pl. VIII, and *E. levis*, 1914, Pl. XII); it would appear from this that the pull of gravity was, at any rate, not being exerted in the same direction as in *E. bigsbyi*. The greater width of interradius I–II in *E. buchianus* also suggests that its position was uppermost, so that the anus lay to the left of the mouth instead of to the right. In genera and species of later date, whether the flexure be solar or contrasolar, we must not expect to find such direct traces of mechanical causes. Those forms, we may most naturally presume, repeat the direction impressed on their ancestors when the conditions of life may have been different; they themselves may emphasize the direction by additional growth, as in the long lash-like grooves of *Dinocystis*, but they are not likely to change it.

Whatever truth there may be in the hypotheses here erected on the suggestive fact of position first recorded by Dr. Foerste, it does at least seem clear that all the differences may very well be due to simple mechanical causes acting on the growing animal. There is no need to invoke any sudden change of structure or constitution, any shuffling of chronosomes, or any reversal of development in early stages, as, for instance, by the splitting of the fertilized ovum into

dextral and sinistral halves. None the less, behind the simple mechanical explanation there still obtrudes the question: Why did one species place itself on a slope with its right side highest, and another species with some other side highest? Or if the external force was not gravity but the constant impact of a current, the question merely has to be posed in another form. There must be an answer to these questions, but we shall not discover it till we know the predecessors of these species, and perhaps not even then.

The Feeding of the Edrioasteroidea, as that of all other Pelmatozoa, was no doubt accomplished by the subvective system of ciliated grooves; but it does not follow that ciliary currents were the only means by which food was transported to the mouth. Reasons have been given for supposing that pores passed from the groove, between the floor-plates, to the thecal cavity in *Dinocystis* (1898, p. 545), in *Edrioaster buchianus* (1900, p. 196), in *E. bigsbyi* (1914, p. 124), and in *Steganoblastus* (1914, p. 198); and it has been argued, from the close similarity of the skeletal structures to those of an Asteroid, that there were external podia connected with internal ampullae. It is not supposed that these podia were provided with suckers, and without them they could not hand morsels of food along the grooves, or even assist the process in the way described by Dr. H. S. Jennings for *Asterias forreri* (1907, Pub. Univ. California, Zool., vol. iv, p. 93). They could, however, have performed some sweeping or pushing action, and may thus have contributed to the supply of food.

Respiration, it is probable, was the primary function of these podia. There is no sign of pores for papulae in any part of the thecal wall, so that these would have been the only extensions of thin-walled cavities available for the interchange of gases. The presence of a distinct hydropore confirms the view that the water-vascular system in these genera carried on some function of importance, whereas in Agelacrinidae the apparent absence of a hydropore is correlated with the absence of pores between the floor-plates.

The view that active podia existed in *Edrioaster* and its like, to which certain facts of structure point, is opposed by other facts of structure, namely, the completeness with which the cover-plates could close down over the grooves, and the position of the pores close up to the hinge-line of the cover-plates. The latter fact led Mr. W. K. Spencer (1904, p. 45) to cast doubt on the existence of podia, and to suppose that the pores had "a respiratory function", which means, apparently, that water was driven through them, by ciliary action (?), into some endothecal cavities not precisely indicated. Pores were supposed by him to be correlated with "firm skeletons", and to be absent from forms with "imbricating plates", which would "present large surfaces of membrane to the surrounding sea-water". This view, however, does not agree with the known facts; besides, the objection is not insuperable. Of course the cover-plates of *Edrioaster* were not closed when the animal was feeding, and it has already been suggested that they might open obliquely so as more readily to allow the podia to pass out between them (1914, p. 162). In the same place attention was directed to the possible openings immediately above the peripodium in *Edrioaster bigsbyi* effected by

accessory cover-plates. Were it not for these accessory plates (1914, p. 165, text-fig. 3) the supposition that the supra-oral cover-plates in that species were suturally united to form a solid tegmen would be inconsistent with the presence of pores all round the peristome.

The Food-grooves of *Edrioaster* and many other Edrioasteroidea are so distinct that they call to mind those structures in Cystidea Rhombifera that used to be called "recumbent arms". Those, however, are produced by the proliferation of circumoral plates over the outside of the theca. The resemblance is really closer to the epithecal grooves of the Diploporita. Their anatomical relations, and, in *E. levis*, their connection with the interambulacrals, show that the floor-plates are part of the thecal wall, not different in origin from the other thecal plates. As in the Diploporita we see to have been the case, so in Edrioasteroidea we may infer that the grooves passed out over the theca from the angles of the mouth, and that as they became deeper and more fixed, and as the cover-plates increased in size, so the subjacent plates became regularized. That is one possible hypothesis, and it seems to be the one held by Dr. Foerste (1914, p. 425). Another hypothesis is that the grooves passed out from the angles of the mouth between the thecal plates and not over them. This view is suggested by the appearances in *Stromatocystis*, and would have the advantage of making the floor-plates a double series from the outset. The disadvantage is the great weakening of the peristomial region which the hypothesis implies.

In any case a stage was reached sooner or later in which the ciliated grooves, with the underlying extensions of the nervous and water-vascular systems, passed over the floor-plates and under the cover-plates as in Diploporita. But from the Diploporita all Edrioasteroidea differ in the absence of exothecal projections (brachioles) bordering the grooves or forming the ends of their branches. From this point of view alone the Edrioasteroidea present an ambulacral structure divergent from that of all other Pelmatozoa, and this is why they have certainly better claims than the Blastoidea, for instance, to rank as a separate class. In those Edrioasteroidea whose skeleton, like that of *Edrioaster*, bears witness to the presence of ampullae, this distinction is enhanced, not changed in character.

The structure of the Peristome has been described for *Edrioaster buchianus* (1900, p. 197, Pl. X, Fig. 2) and *E. bigsbyi* (1914, pp. 164–6, text-fig. 3, Pl. XIV, Fig. 2). It is clear that, as E. Billings noted in 1854, the gullet into which the food-grooves led passed into the stomach through a firmly-built ring or mouth-frame, of which the inner adcentral border turned down so as to form a rim, probably for the attachment of the stomach wall. As viewed from the oral aspect, after removal of all cover-plates, the chief elements of this frame appear to be five perradial plates, of which the exposed portions have a triangular outline. Viewed from the inside of the test, there are also seen to enter into this frame five interradial elements. In all the interradii except the posterior, and in all perradii, these elements appear to be formed of fused portions of floor-plates. In the posterior interradius there also enters into the

frame a portion of the large interradial plate that is pierced by the hydropore-canal.

In the Agelacrinidae an essentially similar peristomial frame has been described, first, obscurely by Miller & Faber in a specimen of *Agelacrinus pileus* (1892 Journ. Cincinnati Soc. Nat. Hist., vol. 15, p. 85, pl. i, fig. 10), secondly, in more intelligent detail from the same specimen, as well as in a specimen of *Streptaster septembrachiatus* by Dr. A. F. Foerste (1914, op. cit., p. 427, pl. i, fig. 5A, pl. ii, fig. 4, and p. 429, pl. i, fig. 7A, pl. iv, fig. 2), who has also favoured me with explanatory diagrams (in litt., 18 Feb., 1915). In the Agelacrinidae, as previously remarked (Study VI, 1915, p. 55) the floor-plates are quadrangular and stretch right across the groove; they may be composed of fused pairs of floor-plates of *Edrioaster* type, but direct evidence for this is lacking. The proximal floor-plate in each ray widens at its proximal or adcentral end, so that these five plates meet, except in the posterior interradius. The adcentral borders of these plates also bend down into the thecal cavity. Thus is formed a roughly circular or sub-pentagonal mouth-frame, similar to that of *Edrioaster* and confirming the interpretation of the radial elements in that genus as fused floor-plates. The gap left in the posterior interradius is filled in by one (*A. pileus*) or possibly more (*Streptaster*) of the posterior peristomial interradial plates, just as in *Edrioaster*. For minor details reference must be made to Dr. Foerste's account; but two structural features seem to have an important bearing.

In the specimen of *Streptaster*, when the mouth-frame is viewed from the inner face, there is seen on the left side of the posterior interradius a curved process, apparently attached to the inner face of the tegmen. This separates "a vertical cavity, less than a millimeter in diameter, apparently leading to the oral surface of the theca" just on the posterior side of ray V, from "a broad inclined groove" leading towards the thecal cavity between rays IV and V. Dr. Foerste's suggestion that this groove served for the passage of the gut seems entirely justified, and confirms the view that the gut had a solar coil. The stereom process served, one may suppose, for the attachment of one end of the posterior mesentery; and the deep narrow passage on the posterior side of it, adjoining ray V, was probably for the passage of a hydropore-canal. That, at any rate, is where such a structure would have lain if it existed.

In the specimen of *Agelacrinus pileus*, the posterior element of the mouth-frame is ridged on its inner face "somewhat like a letter W, the sides of the letter abutting against the thickened inner margins of the adjacent proximal floor-plates" of rays I and V. The middle ridge of the W passes towards the centre of the tegmen; and towards almost the same point are directed similar ridges on the inner faces of the tegminal plates between rays III & IV and III & II respectively. This suggests that the large posterior plate is a compound structure, consisting partly of an interradial element, partly of portions of original paired floor-plates, and partly of the cover-plates which have been transformed on the exterior into the posterior tegminal. Adjoining the margin of this plate where it abuts on ray V, and involving the two proximal cover-plates on the adanal side

of that ray, is "a peculiar margined depression". If, as Dr. Foerste suggests, "a duct passed by this path," then the duct in question would most naturally be the hydropore-canal.

The Relations of the Water-vascular System are of much morphological importance. The most natural interpretation of the appearances in the Edrioasteridae is that the perradial water-vessels lay at the bottom of the subvective grooves, on the ventral side of the abutting floor-plates, and that each gave off alternate branches to podia placed near the outer margin, and that each branch was also connected, through the pore between adjacent floor-plates, with an ampulla lying below (dorsal to) the subvective skeleton. This interpretation will be confirmed by comparison with a modern starfish. The perradial vessels passed to the peristome, and *Edrioaster buchianus* has already yielded evidence (Study II, 1900, p. 198) to show that they were there connected to form a hydrocircus surrounding the opening to the gullet, just above the mouth-frame. The hydropore lay in the posterior interradius, close to ray V, and passed through one or more interradial plates of the theca in a sloping direction from right to left. This direction indicates some torsion of the hydropore-canal and presumably also of the stone-canal, both of which must have been in the thecal cavity. Precisely where they became connected with the hydrocircus we cannot say, but it is plain that connection could readily have been effected by anyone of the ampullar or podial pores, and we may here recall that E. Billings observed a pore in the posterior angle to be larger than the others (Study IV, 1914, p. 164).

In the Agelacrinidae there is no such direct structural evidence for the position or even for the existence of perradial canals, not to mention podia. The shape of the cover-plates in most genera does, however, seem consistent with (one is tempted to say "calculated for") the extrusion of podia between them, and it seems natural to suppose that these structures were present, though unprovided with intra-thecal ampullae. An external hydropore has not as yet been detected, but it is conceivable that the hydrocircus opened into the oral vestibule, and that it may have been connected with some canal passing up in the posterior interradius (*vide supra*).

*Edrioaster*, *Agelacrinus*, and *Steganoblastus* present three modifications of an original subvective skeleton consisting of paired alternating floor-plates and cover-plates. In *Agelacrinus*, where ampullae were still unformed, the floor-plates became partly fused, but were still separated at intervals so as to maintain some flexibility. In *Edrioaster* the development of ampullae and more vigorous podia produced pores and combined with the general flexibility of the test to keep the original floor-plates distinct, except in the mouth-frame. In *Steganoblastus* the ampullae and podia remained, but the floor-plates fused and, in correlation with the rigidity of the theca, formed a single piece stretching right along under the groove.

## IV.—A Contribution to the Petrology of North-Western Angola.

By Arthur Holmes, B.Sc., A.R.C.S., F.G.S., F.R.G.S.

(*Continued from the May Number, p. 232.*)

### 4. Ægirine-Riebeckite Granite from the Lower Congo.
(Pl. XI, Fig. 1.)

THIS remarkable rock occurs as a marginal phase of the granulitic albite granites which are found between Noqui and kilometre 16 on the road to San Salvador. In the hand-specimen it shows a fine-grained slightly foliated structure with a characteristic 'pepper and salt' appearance, due to the sprinkling of lustrous black plates of riebeckite among iron-stained granular crystals of quartz and felspar. A few small porphyritic crystals of orthoclase are embedded in the main mass of the rock, making up approximately 15 per cent of the whole.

The minerals present, and their relative proportions by weight, measured by the Rosiwal method, are as follows:—

| | | |
|---|---|---|
| | Quartz | 32 |
| Alkalic Felspars | Albite + Microcline | 23 |
| | Orthoclase microperthite | 15 |
| | Microcline microperthite | 10 |
| | Riebeckite | 16 |
| | Ægirine | 4 |
| Accessory Minerals | Zircon, Ilmenite, Limonite, Sericite or kaolin (?) | n.d. |
| | Total | 100 |

A separation was effected by means of Klein's solution, which was gradually diluted with water. Specific gravity measurements were made with a Westphal balance at each critical point.

| *Specific Gravity.* | *Minerals.* |
|---|---|
| 3·441 | Ægirine (3·5) sank. |
| 3·381 | Riebeckite sank. |
| 2·645 | Quartz sank. |
| 2·599 | Albite sank. |
| 2·545 | Orthoclase and microcline sank. |

Special care was taken to examine the grains which fell at 2·645 for oligoclase, but none could be detected. The absence of oligoclase was further verified by refractive index measurements. Using clove-oil ($\mu = 1{\cdot}544$) only quartz among the colourless essential minerals give a higher value. Using monochlor benzine ($\mu = 1{\cdot}527$), albite gave a higher value, orthoclase and microcline a lower one.

*The felspars*, with the exception of the larger microperthite crystals, form with quartz a fine-grained glassy mosaic, the constituents of which give sharp extinctions between crossed nicols with no trace of strain shadows. The porphyritic crystals, on the contrary, do show strain phenomena. They have ill-defined borders, owing to interlocking

with the surrounding mosaic, and in one case it was noticed that a long tongue of the latter, heavily charged with vermicular limonite and minute zircons, had cut transversely across the crystal. The porphyritic crystals are twinned according to the Carlsbad law, and are made up of orthoclase with microperthitic streaks of albite. Inclusions of riebeckite needles, and patches and blebs of limonite follow the lines of perthitic intergrowth, and are commonly, but not invariably, arranged in linear groups. Here and there irregular aggregates of an indeterminable mineral, which may be kaolin or sericite, can be seen. Similar inclusions occur in the microcline and albite of the mosaic, but they are less abundant than in the larger perthites.

Intermediate in size between the porphyritic crystals and those of the mosaic are a few allotriomorphic individuals of microcline perthite. The 'cross-hatching' of the microcline is somewhat patchy, and may be absent altogether. Feeble strain shadows are seen in some cases, but in others the extinction is sharp.

The felspars of the mosaic are exclusively microcline and albite. An analysis of the rock indicates that the albite molecule may be accompanied by a very small proportion of anorthite. Making allowance for the fact that more than half of the CaO in the rock is probably present in riebeckite and ægirine, the albite can scarcely be more calcic than $Ab_{96}\ An_4$. Both orthoclase and microperthite are entirely absent from the mosaic, and microcline is much less abundant than albite. The felspars are generally allotriomorphic, but sometimes they exhibit crystal planes in contact with quartz.

The larger felspar crystals are predominantly of orthoclase, accompanied by a little perthitic albite; those of intermediate size are chiefly of microcline, again accompanied by perthitic albite. Among the smaller individuals albite is predominant, microcline is subsidiary, and perthitic intergrowths are absent. It would be unwise to assume too much from a single specimen of the rock, but the restriction of strain phenomena to the larger crystals suggests that the mosaic felspars may be partly the result of the granulation, recrystallization, and albitization of the older orthoclase perthites. A similar explanation of the structures and composition of the Quincy riebeckite granite has been given by Warren.[1]

*Quartz* is the most abundant mineral in the rock, making up about 60 per cent of the colourless constituents of the mosaic. It is present in allotriomorphic equidimensional grains which exhibit no unusual features.

*Riebeckite* is present to the extent of about 16 per cent of the whole rock, an unusually high proportion for a rock of this type. It varies in size from tiny microscopic needles and irregular shreds to larger crystals which tend towards a prismatic habit, but which generally have ragged edges. In transverse sections the average area is much the same as that of the quartz and felspars of the mosaic, but it is subject to greater variation. The prism and clinopinacoid edges can sometimes be identified. Longitudinal sections are elongated, the

[1] C. H. Warren, Proc. Am. Acad. Arts and Sci., vol. xlix, No. 5, p. 215, 1913.

maximum dimension being about two millimetres. Intergrowths with ægirine were not observed, but occasionally a thin fringe of ægirine, or of minute fibres of limonite, separates the riebeckite from the other minerals. Patchy inclusions of quartz and felspar, minute prisms of zircon, and small grains of ilmenite (?) break up the continuity of the riebeckite individuals, but the mineral has not the spongy appearance which is its customary habit.

The pleochroism and optical orientation were determined from longitudinal and transverse sections. Faint indications of biaxial interference figures were seen in the latter in very thin sections, from which it was determined that the plane of the optic axis bisects the *acute* angle between the cleavages. The maximum extinction angle $X \wedge c$ is about 5°. The pleochroism is as follows: $X$ (nearly = $c$), deep ultramarine blue; $Y$ (nearly = $a$), yellowish green; $Z$ (= $b$), smoky greenish blue. $Z > X > Y$. The colour is generally patchy, and grey and violet tints are sometimes seen in intermediate positions between $X$ and $Y$. The birefringence is very low.

In almost every respect, and notably in the position of the optic axial plane, which is parallel to the orthopinacoid, the Angola riebeckite bears a striking resemblance to that of the Quincy granites.[1] In the latter case the composition was approximately $Na_2 Fe_2 (Si O_3)_4$, 42 per cent; $R_4 (Si O_3)_4$, 56 per cent, in which R is chiefly Fe accompanied by smaller amounts of Ca, Mn, and Mg; with excess of 2 per cent of $Si O_2$. This is an unusually high percentage of the $R_4 (Si O_3)_4$ molecule, but the exceptionally high content of ferrous iron in the Angola rock suggests that there the $R_4 (Si O_3)_4$ molecule is equally abundant. Unfortunately the material available was insufficient to allow an analysis of the separated riebeckite to be made.

*Ægirine* makes up about 4 per cent of the rock. The crystals are very irregular and broken in appearance, except where the mineral occurs as tiny inclusions which are elongated along the vertical axis. There is a tendency for small fragmentary ægirines to occur in groups which extinguish nearly, but not perfectly, as a whole. Many of the crystals are veined with ferruginous matter, which also collects round the edges in thin fibres and minute acicular projections. The pleochroism is as follows: $X$ (nearly = $c$), grass green or blue green; $Y$ (= $b$), yellow green; $Z$ (nearly = $a$), straw to pale yellow green. $X > Y > Z$. The maximum extinction angle between $X$ and $c$ is about 9°, showing that the ægirine is not quite pure.

*Zircon* is present in extremely minute crystals which are present as inclusions in all the minerals, but more particularly in the soda-bearing minerals. As in the case of rockallite[2] the total amount of zircon present is manifestly insufficient to account for the percentage of zirconia found in the rock by analysis. In this case the zirconia must enter into the composition of the riebeckite. The association of zirconia with riebeckite has been frequently pointed out.[3] Parisite,

[1] Warren & Palache, Proc. Am. Acad. Arts and Sci., vol. xlvii, No. 4, p. 152, 1911.

[2] Washington, Q.J.G.S., vol. lxx, p. 298, 1914.

[3] For references and discussion see Murgoci, *Am. Journ. Sci.*, vol. xx, p. 137, 1905.

which is a characteristic associate of riebeckite, though a very rare mineral, was looked for, but could not be identified with certainty. Tiny grains of ilmenite peripherally altered to leucoxene are present, included in or near to riebeckite.

Ferruginous stains occupy the borders between many of the crystals, and vermicular aggregates and fibrous coatings of the same material have already been mentioned. Both the colour, and the excess of combined water in the rock over that required for riebeckite, point to limonite as the identity of this mineral. The rock shows no trace of weathering alteration, and it is possible, as Murgoci has suggested,[1] that the limonite is primary, and that it now directs attention to areas which at the moment of consolidation were still more or less impregnated with iron compounds and water vapours.

*Chemical Characters and Classification.*—A chemical analysis of the rock was made by the methods advocated by Washington. The results are given below, together with the norm and the position of the rock in the Quantitative Classification. The rock falls into the subrang Varingose (II, 3, 1, 3) on the side of Grorudose (II, 4, 1, 3), which differs from the former only in the inferior ratio of quartz to felspar.

| *Analysis.* | | *Norm.* | | |
|---|---|---|---|---|
| $SiO_2$ | 74·66 | Quartz | 35·38 | Salic = 83·10 |
| $Al_2O_3$ | 8·85 | Orthoclase | 26·13 | |
| $Fe_2O_3$ | 3·26 | Albite | 20·96 | |
| $FeO$ | 3·54 | Zircon | 0·63 | |
| $MgO$ | 0·09 | | | |
| $CaO$ | 0·53 | Acmite | 8·78 | Femic = 16·67 |
| $Na_2O$ | 3·68 | Diopside | 2·23 | |
| $K_2O$ | 4·46 | Hypersthene[2] | 4·82 | |
| $H_2O$ (115°+) | 0·67 | Magnetite | 0·23 | |
| $H_2O$ (115°−) | 0·08 | Ilmenite | 0·61 | |
| $TiO_2$ | 0·32 | | | |
| $ZrO_2$ | 0·51 | | 99·77 | |
| Total | 100·65 | | | |
| Sp.gr. | 2·55 | | | |

Class II, Dosalic.
Order 3. Quarfelic.
Rang 1, Peralkalic.
Subrang 3, Sodipotassic.
II, 3, 1, 3, VARINGOSE.

A number of analyses of other riebeckite and ægirine granites is listed below for comparison with the Angola example. It will be noticed that with the incoming of riebeckite the proportion of ferrous iron relative to ferric is increased, and moreover that a high proportion of ferrous iron is consistently accompanied by a superiority of potash over soda. Analysis III, that of the Angola rock, falls into the same subrang as that of the Grorudite from Varingskollen. The two analyses are strikingly similar, and the total iron contents are practically identical. There is, however, a sharp difference in the relative proportions of ferrous and ferric iron, a difference which

[1] Murgoci, p. 145.
[2] Practically all $FeSiO_3$.

corresponds to the distinction in mineral composition between the two rocks. Compared with other riebeckite granites, it is clear from analyses, modes, and norms that the Angola rock is richer in riebeckite than any other granite hitherto described.

| Constituents. | Ægirine-acmite Granites. | | Ægirine-Riebeckite Granites. | | | | Riebeckite Granites. | |
|---|---|---|---|---|---|---|---|---|
| | I. | II. | III. | IV. | V. | VI. | VII. | VIII. |
| $SiO_2$ . | 69·80 | 74·35 | 74·66 | 73·80 | 75·25 | 74·86 | 76·49 | 68·54 |
| $Al_2O_3$ . | 5·10 | 8·73 | 8·85 | 11·90 | 11·60 | 11·61 | 11·89 | 15·47 |
| $Fe_2O_3$ . | 13·23 | 5·84 | 3·26 | 1·90 | 0·78 | 2·29 | 1·16 | 2·03 |
| FeO . | 0·78 | 1·00 | 3·54 | 1·91 | 3·00 | 1·25 | 1·56 | 2·09 |
| MgO . | 0·11 | 0·07 | 0·09 | 0·33 | 0·39 | 0·05 | tr. | 0·21 |
| CaO . | 0·72 | 0·45 | 0·53 | 0·30 | 0·70 | 0·41 | 0·14 | 0·30 |
| $Na_2O$ . | 8·04 | 4·51 | 3·68 | 5·05 | 3·98 | 4·30 | 4·03 | 5·68 |
| $K_2O$ . | 0·22 | 3·96 | 4·46 | 4·93 | 4·20 | 4·64 | 5·00 | 5·75 |
| $H_2O+$ . | 0·46 | 0·25 | 0·67 | 0·13 | — | 0·31 | 0·38 | 0·59 |
| $H_2O-$ . | 0·31 | — | 0·08 | 0·04 | — | 0·04 | 0·12 | |
| $TiO_2$ . | 0·34 | — | 0·32 | 0·23 | 0·19 | 0·20 | tr. | 0·14 |
| $ZrO_2$ . | 1·17 | — | 0·51 | 0·04 | — | 0·20 | — | — |
| $P_2O_5$ . | 0·07 | — | n.d. | — | — | tr. | — | 0·10 |
| $Ce_2O_3$ . | 0·37 | — | n.d. | 0·04 | — | — | — | — |
| MnO . | 0·12 | 0·22 | tr. | 0·12 | — | 0·02 | tr. | — |
| Totals | 100·84 | 99·38 | 100·65 | 100·72 | 100·09 | 100·18 | 100·77 | 100·90 |
| Magmatic Symbols & Names. | III, 3, 1, 3 Rockallose. | II, 3, 1, 3 Varingose. | II, 3, 1, 3 | I, 4, 1, 3 | I, 4, 1, 3 | I, 4, 1, 3 Liparose. | I, 4, 1, 3 | I, 4, 1, 3 |

I. *Rockallite.* Rockall. H. S. Washington, analyst. Q.J.G.S., vol. lxx, p. 297, 1914.

II. *Grorudite.* Varingskollen, Norway. G. Särnström, analyst. Brögger, *Zeit. Krist.*, vol. xvi, p. 66, 1890.

III. *Ægirine-Riebeckite Granite.* Congo, Angola. Arthur Holmes, analyst.

IV. *Ægirine-riebeckite gneiss.* Carn Chuinneag, Ross-shire. W. Pollard, analyst. Mem. Geol. Surv. Scot., Sheet 93, p. 92, 1912.

V. *Ægirine-Riebeckite Granite.* Zinder. Between Lake Tchad and Sokoto. Lacroix, C.R., vol. cxl, p. 22, 1905.

VI. *Ægirine-Riebeckite Granite.* Quincy, Mass. Mean of three analyses by C. H. Warren and H. S. Washington. Warren, Proc. Am. Acad. Arts and Sci., vol. xlix, p. 227, 1913.

VII. *Paisanite.* Magnolia, Essex Co., Mass. H. S. Washington, analyst. *Journ. Geol.*, vol. vii, p. 113, 1899.

VIII. *Riebeckite Granite.* Ekona, Sungale, Kamerun. Rosenbusch, loc. cit.

Corresponding with the high riebeckite content of the rock is its comparative richness in zirconia. The ratio of riebeckite to zirconia in the Quincy granite (analysis VI) is practically identical with that of the Congo rock.

Granites containing both riebeckite and ægirite or acmite are somewhat rare, and in addition to the four examples of which analyses have been quoted the only others of which I have succeeded in finding a record are from the following localities:—

Dahamis, Socotra: riebeckite-acmite granite.[1]
Cevadaes, Portugal: ægirine-riebeckite granulite.[2]
Narsarsuk, Greenland: ægirine-riebeckite granite.[3]
Shira and Kila, Northern Nigeria: ægirine-riebeckite granites.[4]
Ampasibitika, Madagascar: ægirine-riebeckite granite.[5]

Although the ages of these nine rocks are not yet known except within broad limits, it is clear that they range from late Archæan to early Tertiary, and it is interesting to notice that, rare as it is, ægirine-riebeckite granite is a type which has recurred at widely different periods and in widely separated localities.

Granites containing riebeckite or ægirine are not rare in West Africa. They occur with ægirine rhyolites and alkaline trachytes in the Shari basin (Mburao and Melfi) and at Hadj el Hamis on the south-east of Lake Tchad.[6] At Zinder and Mounio, west of Tchad, riebeckite, ægirine, and ægirine-riebeckite granites are associated with rhyolites of corresponding composition,[7] and further to the north, in the Saharan complexes of Ahaggar and Air, ægirine rhyolites are found.[8] Riebeckite granites are known from Feta in Dahomey, and they are well represented in Nigeria in the Gurkawa Hills, on the Bauchi plateau, near the borders of Bauchi and Kano, and at Shira in Katajum.[9] Unfortunately the ages of these rocks are not yet known with certainty. The volcanic rocks appear to be early Tertiary, but the granites may lie anywhere between late Pre-Cambrian and early Tertiary.

## EXPLANATION OF PLATE XI.

FIG. 1.—Ægirine-riebeckite Granite, near kilometre 16, on the road from Noqui to San Salvador, Congo, Angola, showing riebeckite in longitudinal sections, and allotriomorphic quartz and felspar with films of limonite between adjacent individuals.

FIG. 2.—Nepheline Syenite (Foyaite), near kilometre 24, on the road from Senza do Itombe to Bango, Loanda, Angola; showing nepheline (clear except along cracks) and orthoclase (cloudy), with a characteristic group of ægirine augite bordered with hastingsite and sphene.

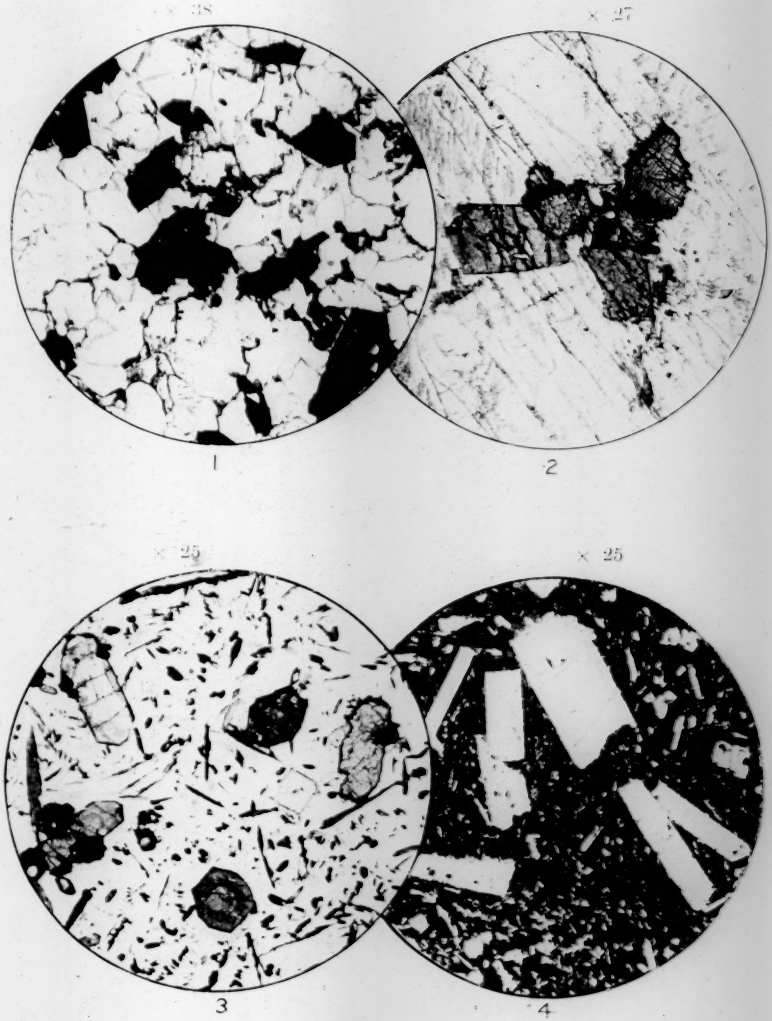
FIG. 3.—Nepheline Monchiquite, near kilometre 20, on the Senza-Bango road, showing phenocrysts of amphiboles and pyroxenes and wisp-like ferns embedded in a clear groundmass of nepheline and of what is probably analcime.

FIG. 4.—Nepheline Phenolite, near kilometre 22, on the Senza-Bango road, showing phenocrysts of nepheline in a dark groundmass which includes ægirine augite and a yellow-brown isotropic base.

Ordinary light and magnification 40 in each case.

The photo-micrographs were made for me by Mr. G. S. Sweeting, of the Geological Department of the Imperial College, to whom my best thanks are due.

[1] Rosenbusch, *Elemente d. Gesteinslehre*, p. 86, 1910. Analysis by Ludwig.
[2] Osann, *Neu. Jahre Min. Geol.*, etc., 1907, p. 109 (2); de Sousa, C.R., vol. clvii, p. 1451, 1913.
[3] Flink and Böggild, *Meddelelser om Grœnland*, p. 24, 1899.
[4] Falconer, *The Geology and Geography of Northern Nigeria*, p. 133, 1911.
[5] Lacroix, Nouv. Arch. Mus. Hist. Nat., sér. IV, p. 164, 1902.
[6] Gentil & Freydenberg, Bull. Soc. Géol. France, sér. IV, viii, p. 35, 1908.
[7] Chudeau, Sah. Lond. 1909, p. 266.
[8] Chudeau, op. cit., p. 258.
[9] Falconer, *The Geology of Northern Nigeria*, pp. 133–4. See p. 135 for other references.




ALKALINE IGNEOUS ROCKS from North Western Angola.

## V.—"Radio-activity and the Earth's Thermal History": A Criticism.

By Professor A. P. Coleman, M.A., Ph.D., F.R.S., University of Toronto.

IN the very interesting paper by Mr. Arthur Holmes on "Radio-activity and the Earth's Thermal History", in the Geological Magazine for February and March, it is assumed that in Archæan times there was "a widespread molten condition at no very great depth" below the earth's surface, and in the final conclusions the statement is made that "geological and other evidence points favourably to the traditional view that the earth's crust was initially in a molten state". The results of recent work on the Archæan of Canada do not bear out this traditional view of the conditions of the earth's earliest known geological period, and it may not be amiss to suggest some points that decidedly conflict with it.

The earliest rocks known on the Canadian Shield are the Coutchiching, the Keewatin, and the Grenville Series. The Coutchiching consists entirely of metamorphosed muddy and sandy sediments, the Keewatin includes mainly volcanics, but also considerable amounts of sediments, and the Grenville is essentially sedimentary and consists largely of limestone. These three groups of rocks seem to have been formed in succession with no great break in time. Lawson has shown that the Coutchiching, in part at least, underlies the Keewatin, and Miller and Knight have found that in Eastern Ontario the Grenville overlies Keewatin volcanics, apparently conformably. All of them antedate the batholithic eruptives, which have upheaved and penetrated them. They were therefore deposited before the earliest known acid plutonics, generally called Laurentian, had begun their ascent beneath the Archæan mountain ranges.

Lawson gives the Coutchiching sediments of Rainy Lake a thickness of 4½ miles, and the Keewatin volcanics he describes as equally thick. In other Keewatin regions 1,000 or more feet of "iron formation" as well as important amounts of other sediments are found associated with the Keewatin and should be added to the total. The Grenville of the Haliburton region in Eastern Ontario is believed by Adams to be 90,000 feet in thickness, the greater part consisting of limestones.

It will be seen, then, that before the first known batholithic mountain building began there were on the surface of the earth many thousands of feet of sedimentary and volcanic rocks. It may be objected that the thickness of these ancient and much metamorphosed rocks has perhaps been over-estimated, but it must be remembered on the other hand that they are known to us only as remnants, since the great mountain ranges of the early Archæan had been reduced to a peneplain before the beginning of the Huronian. It is most unlikely that the whole thickness of these rocks has been anywhere preserved.

But there is another point of equal importance to be considered. The floor on which these great beds of sediments and volcanics were deposited has nowhere been found, though it must have been thick and solid to support their weight; and the great areas of dry land

whose weathering furnished the hundreds of cubic miles of mud and sand of the sedimentary rocks have likewise vanished. There must have been thousands of feet of solid rock beneath the seas and the continents of the time, but these seem to have been melted and set in motion as the materials of the batholithic granites and syenites that came later. The batholiths have even stoped down and encroached upon the lower portions of the Coutchiching, Keewatin, and Grenville as well; so that to find the original thickness of the first known crust of the earth one must add many thousands of feet to the estimates given above.

Finally, it must be recalled that water existed as a liquid at the very beginning. The rocks forming the basins were not warm enough to evaporate the seas of the time; and in both the Keewatin and the Grenville there are important beds of sediments containing five or ten per cent of carbon, strongly suggesting algæ or some other form of plant life. It may be that the limestones also were formed by the aid of plants or animals. If life existed in the seas, as seems very probable, the temperature of the earth's surface was not higher than living beings can endure, and we may fairly assume that conditions were not widely different from those of later geological periods.

With conditions such as have just been described in early Archæan time there is no good reason to suppose that the molten magma was near the surface. It was probably as far below as in later ages or at present. The great abundance of Archæan granites and orthogneisses simply means that, in the most ancient regions of the world, erosion has gone to greater depths than elsewhere. The same types of plutonic rocks are found at many later ages, though naturally they are not so extensively exposed, since the overlying rocks have undergone less destruction. Batholiths of Mesozoic granite and diorite cover 50,000 square miles of the coast ranges of British Columbia and have precisely the same habit as the Laurentian. There is, in fact, no geologic reason for supposing that the earth had a higher temperature in the Archæan than at any later time. If the earth was ever a molten globe it had so far cooled down in the earliest known geological times that life probably existed, that water and air did their work just as in later ages, and that an immense thickness of sediments and lavas could be deposited on a firm foundation of still earlier rocks.

## VI.—The Coastal Series of Sediments in the East Africa Protectorate.

By H. B. Maufe, B.A., F.G.S., Director of the Geological Survey of Southern Rhodesia.

IN his report on "The Coal Resources of the East Africa Protectorate" published in the Twelfth International Geological Congress' *The Coal Resources of the World* (vol. ii, p. 381), Dr. J. W. Evans discusses evidence bearing on the existence of coal in the Taru Grits, which form the lowest member of the coastal series of sediments in the East Africa Protectorate. Referring to a report of mine,[1] he

[1] Report relating to the Geology of the East Africa Protectorate. *Colonial Reports, Miscellaneous*, No. 45, 1908.

remarks that I believe them to be of Karroo age, and then says, "E. Fraas, who subsequently made a brief examination of the line of railway, and whose account of the geology of the region differs in many respects from that of Maufe, refers them to the Middle Dogger (Inferior Oolite)."[1]

I cannot explain how Fraas' paper came to be overlooked by me, or that author's reading of the structure and succession would certainly have been challenged at once. Fraas' examination was made whilst detained in Mombasa for a day or two waiting for a steamer. He apparently travelled up and down the Uganda Railway by train, and was able to make excursions from a couple of the stations. I had the advantage of several weeks on the ground, both trolleyed and walked the whole line, and made several traverses out on both sides where sections might be seen on the flanks of valleys.

Between Voi (mile 102) and Kilindini on the coast Fraas makes seven rock groups, which in ascending succession are as follows: (1) Crystalline basal rocks, (2) Karroo sandstone, (3) Middle Dogger, (4) Upper Dogger, (5) Malm, (6) Cretaceous sandstone, (7) Pleistocene reef limestone.

According to Fraas' description and section the crystalline basal rocks crop out at Voi, and the dip being eastwards towards the coasts the other groups outcrop in order in that direction with the exception of (6) Cretaceous sandstone, which, owing to a supposed flattening of the dip, does not reach the coast. The Pleistocene reef (7) rests unconformably against his (5) Malm.

Between Voi and Maungu, the next station towards the coast at mile 84, Fraas states that (2) Karroo sandstone crops out, and also says, "South of the railway the Maungu Mountains rapidly rise to a height of 1,000 metres. We easily recognize these as sandstone mountains with horizontal stratification, and a light-coloured, cross-grained sandstone is to be seen along the railway." I climbed these 'mountains' and found them to consist of a foliated hornblende-biotite-gneiss (Report, p. 19). Also, I am sure the whole distance from Voi to beyond Maungu is underlain by gneiss, and any sandstone seen beside the railway must have been brought there for construction.

At Mombasa Fraas saw a big trunk of silicified wood which he was told came from this region. The trunk is without doubt one which I dug out of his (6) Cretaceous sandstone and took down to Mombasa station. (Report, p. 9.)

Around Samburu (mile 41) he notes the hard micaceous sandstones which he says are (3) Middle Dogger. These are my Taru Grits, which were being quarried for the Kilindini harbour works. He examined them more closely there, and found poor impressions of Calamite-like stems, and fragmentary leaf-remains, also one cross-section of a Belemnite and one skeleton impression of an Ammonite. I saw only obscure plant-remains and black carbonaceous specks in the beds at Samburu. Beyond Samburu Fraas identifies from the train the sandstones of the Upper Dogger (4). These are probably the lower part of the Maji-ya-Chumvi Beds, in which I found *Thuyites* and *Carpolites*.

[1] *Centralblatt für Mineralogie*, etc., 1908, p. 641.

At the station of Maji-ya-Chumvi (mile 33) Fraas notes greasy brown marls, said to be of Oxford and Kimmeridge age (group 5), which without doubt are a part of my Maji-ya-Chumvi Beds. Fraas saw no fossils here, but identifies them with a part of the marine fossiliferous Changamwe Shales of Mombasa Harbour. Not only are they distinct lithologically, in being dull greenish mudstones with numerous thin beds of very hard sandstone, but in place of the Ammonites and Belemnites found in the Changamwe Shales I obtained *Estheria* near Maji-ya-Chumvi. After the description by Mr. R. B. Newton of a new species of *Estheriella* discovered by Messrs. Andrew and Bailey in the Karroo rocks of Nyassaland,[1] Mr. Newton kindly examined the Maji-ya-Chumvi specimens, and wrote: "I am inclined to regard them as carapaces of a form closely allied to *Estheria greyi*, T. Rupert Jones, from Cradock, South Africa. I should regard them also as of similar age to those found by Molyneux in Rhodesia, as well as those discovered by Andrew & Bailey in Nyasaland." This I think makes it clear that the Maji-ya-Chumvi Beds cannot be correlated with the marine Changamwe Shales of Upper Jurassic age.

Above the Maji-ya-Chumvi Beds come sandstones, which Fraas, as a result of his identification discussed in the preceding paragraph, places above the Changamwe Shales and calls Cretaceous. These sandstones were divided by me into two groups, the Mariakani Sandstones below and the Mazeras Sandstones above. I found that the Mazeras Sandstones dipped below the Changamwe Shales, a clear section being seen in the estuary of the Mwachi River, south of the railway. Fraas' statement that the sandstones overlie the shales and cap the ridge along which the railway runs from Mazeras down to Changamwe is contrary to fact. The Shales at Changamwe are covered only by 6 or 8 feet of loam, which extends in this manner inland for 5 miles. The shales then appear on the surface and in cuttings for about 2 miles, when the upper beds of the Mazeras Sandstones rise from beneath them. The dip of the shales in this section is much above the average, being often 25° instead of the usual 10°. Shortly after passing on to the Mazeras Sandstone the dip flattens and is less than the normal. The overlooking of this change of dip has probably been the cause of the error in supposing that the sandstones overlay the shales with marine fossils. The presence of silicified wood, as noted above, in these sandstones, and their interstratification with bright green and purple sandstones point to the persistence of lagoonary or continental conditions until the close of the period of their deposition. Marine conditions come on for the first time on this coast with the Changamwe Shales, for near their base are two beds of limestone, the upper of which contains an unidentified lamellibranch. It is quite possible that this limestone is on the same horizon as the fossiliferous Bathonian limestone, apparently faulted in amongst Upper Jurassic shales, about 5 kilometres inland from Tanga, German East Africa.[2] The fossils which Fraas actually obtained all came from the well-known locality on the

[1] Quart. Journ. Geol. Soc., vol. lxvi, p. 244, 1910.
[2] W. Koert, *Zeitsch. der deutsch. geol. Ges.*, vol. lxi, p. 150, 1904.

Upper Jurassic horizons high up in the Changamwe Shales.[1] He obtained no more marine fossils from any of his supposed Cretaceous Malm, Upper Dogger, or Middle Dogger horizons anywhere inland from Mazeras, with the exception of the cross-section of a Belemnite and skeleton impression of an Ammonite, mentioned above as from material brought down to Kilindini harbour works. As the supposed horizon is several hundred feet below beds containing *Estheria*, it may be assumed that, if the identification of Belemnite and Ammonite is correct, the material has been referred to a wrong horizon, even as the fossil trunk brought down at Mombasa was thought to come from the Maungu gneiss.

Lamellibranchs (*Exogyra*, etc.), claimed to indicate an Aptian horizon, have been found north of Mombasa Island, but they were obtained from the top of the Changamwe Shales, not from the Mazeras Sandstones. No palæontological evidence exists for believing that Cretaceous rocks are exposed on the line of the Uganda Railway. On the other hand, from the gneiss inland to the coast there is an upward succession of grits and sandstones with shales, containing only plant-remains and *Estheria*, until the limestones at the base of the Changamwe Shales are reached, when marine fossils appear for the first time. The age of the lowest marine horizon has not been determined, but the higher fossiliferous beds indicate Upper Jurassic.

Professor Haug has inserted Fraas' horizontal section in his *Traité de Géologie*, vol. ii, p. 1043, but the accompanying description, giving lists of marine fossils of Bathonian, Callovian, and Oxfordian ages, refer to discoveries said to have been made in German East Africa, and is consequently most misleading. One would think that *Pseudomonotis echinata* had been found where gneiss actually crops out, and that Callovian fossils had been obtained from beds in which I obtained *Estheria* and *Thuyites*.

## REVIEWS.

I.—Physical Geography. By Philip Lake, M.A. pp. xx+324. Cambridge University Press, 1915.

THIS textbook of Physical Geography is intended for the more advanced students in schools, yet its standard is sufficiently high to be of value to teachers as well. Since the author is both a practical geographer and geologist, as well as a teacher, we find that his treatment of the subject maintains a fairly even balance between these two branches of science.

The subject of environment, or the influence of Nature, and contact with other beings, upon the individual, is not discussed: the book, therefore, lacks the human element, and may prove a disappointment to a certain section of the geographical school, which at times is rather apt to construct plausible theories based upon insecure foundations. Mr. Lake has rather aimed at instilling into his readers a fairly deep knowledge of the natural phenomena likely to be experienced at any particular part of the globe, leaving the effects of environment to be deduced by the students themselves.

[1] Futterer, *Zeitsch. der deutsch. geol. Ges.*, vol. xlvi, p. 1, 1893.

The book is divided into three parts, dealing respectively with the atmosphere, the ocean, and the land. Of these, the first part (114 pp.) is largely meteorology, which receives much fuller treatment than is usual in a textbook of this class. It is perhaps all to the good, for meteorology is a branch of the subject which has been much neglected in the past, whilst recent advances in our knowledge of the atmosphere throw welcome light upon that varying combination of phenomena we call *weather*, and help us to value rightly the processes of *weathering* and *sculpture* of the rocks in different parts of the world. The influence of atmospheric pressure upon the weather is clearly propounded, and the migrations and changes of the belts of pressure, wind, and rain, with the apparent movements of the sun, are well described and illustrated by diagrams.

The part dealing with the ocean is shorter in length (78 pp.), but quite adequate. A valuable chapter is that upon waves and tides, with a special section devoted to those in British seas.

Although the third part of the book is the longest (125 pp.), we notice in it signs of great compression, as if the author had been compelled to reduce his manuscript to a much smaller compass than he desired. Some sections, therefore, are poor, and the manner of expression not always happy. Thus, in describing faults, reversed faults are omitted, although thrust-planes are mentioned. A better geological section than that of the thrust-plane of the Ardennes and Belgian Coal-field (is this a 'war' section?) might have been chosen from the North-West Highlands.

The differences between local 'volcanic-quakes' and the great 'earth-shakers' are not made clear in the description of earthquakes.

In the chapter on rivers there is again ambiguity, owing to want of clarity of expression, especially in sections dealing with the erosion of a river and grading of the river channel. One of the best chapters in the book is that dealing with the development of river-systems, those of Northumberland, the Humber, and the Weald receiving special notice.

Under "Snow and Ice" glaciers receive little attention. It should be pointed out that the largest (Antarctic) bergs are composed of snow, and float with considerably more than one-ninth of their bulk above water.

In the chapter on volcanoes more might have been said about the ancient volcanoes of the British Isles. It seems necessary to emphasize that most of our mountains of volcanic origin are merely carved out of piles of volcanic debris. To many people a cwm, or corrie, in a shapely hill, must be an old volcanic vent.

An appendix of C.G.S. units used by the Meteorological Office in its daily weather report, a list of works of reference, and an index conclude a book that can be thoroughly recommended for the purpose for which it was written. The photographic illustrations are good, but too few in number; they are, however, supplemented by many well-drawn figures in the text, and seven world-maps dealing with pressure, temperature, and rainfall.

B. S.

II.—The Geology of Caithness. By C. B. Crampton and R. G. Carruthers; with contributions by John Horne, B. M. Peach, John S. Flett, and E. M. Anderson. Memoirs of the Geological Survey of Scotland (Sheets 110 and 116, with parts of 109, 115, and 117). pp. viii and 194. 1914.

THE appearance of this memoir marks an important advance in our knowledge of the geology of the north-east of Scotland. It deals mainly with the Caithness Flags and the strata associated with them, freshwater rocks of exceptional lithological character, and presenting problems of the greatest interest. Dr. Strahan tells us in his preface that the survey was long in progress, so long that as the services of many of those who took part in it were no longer available some re-examination of the area mapped by them became necessary, conditions unfavourable for uniformity and completeness, but they have not seriously affected the value of the work.

In his introductory chapter Dr. Flett formally accepts the Middle Old Red Sandstone age of the Orcadian rocks, though there is nothing in the evidence at present available, which is inconsistent with an attribution of the unfossiliferous rocks below the unconformity at the base of the Berriedale and Ellensgoe conglomerates to the Lower Old Red Sandstone. Of especial interest is the regular rhythm of sedimentation in the Caithness Flags, each cycle having a thickness of from 35 to 65 feet. This recurrence is considered to be the result of warping, but it seems more probable that it is due to periodic variations in meteorological conditions. It is a great misfortune that the untimely death of Dr. Traquair has left the evidence for the zoning of these rocks by means of their fish-remains in an incomplete state. There can be no doubt that the special fauna of the John o' Groat's Beds is of true zonal significance, but it is by no means clear how far this is the case with other variations in the species of fish which are present. Full details are given of the important discovery of the Achanarras fauna at Niandt on the east coast. It is difficult, however, to correlate the account of the beds at Achanarras with that given by Dr. Traquair, who saw them under more favourable circumstances. This account might well have been reproduced, as the Proceedings of the Royal Physical Society of Edinburgh are not accessible to most readers. It is curious that capitals are retained in this memoir in specific names, though they have long since been abandoned in Survey memoirs dealing with England and Wales. A number of plant-remains have been described from the Caithness Flags, but the names of none of these appear in the memoir, though we are informed that the plants collected were submitted to Dr. Kidston for identification.

One of the most striking features of the Orcadian rocks of Caithness is their enormous thickness, which has been estimated at from 16,000 to 18,000 feet, which, however, includes 5,000 feet attributed to the Thurso Flags. The present writer has given reasons for believing that this is excessive, and the evidence furnished by the memoir points in the same direction. The question is complicated by the extent to which the rocks in the interior are obscured by Quaternary deposits, the repetition and lateral variation of lithological characters, the

infrequency of fossils, and the possibility of the occurrence of undetected faults.

The igneous rocks intrusive in the Old Red Sandstone include monchiquite and nepheline basalt, allied to the dykes of the Orkneys.

Second only to the Orcadian rocks in interest are the glacial phenomena, which are dealt with in considerable detail, and a full account is given of the transported mass of Lower Cretaceous age found at Leavad. The absence in Caithness of the 100 foot and 50 foot raised beaches that are so characteristic of the Scottish coasts is attributed to a covering of ice, but it is possible that the former may be represented by the beach found at a height of from 5 to 8 feet above the sea, for there is evidence of recent depression.

The colour-printed sheets 110 and 116 mark a great advance on the hand-coloured sheet 115. It is a pity it was necessary to employ the dark tints which have been allocated to Devonian rocks and render the topography difficult to read, and the difficulty is increased by the shading indicating the Quaternary deposits. A small area south of the Stacks of Duncansby is wrongly coloured as Caithness Flags instead of John o' Groat's Sandstone. This has been set right in type, but was correctly mapped nearly a quarter of a century ago. It is interesting to note that after employing in turn white, black, and blue for faults the Survey has now adopted dark reddish brown for the same purpose. The only drawback is that it rather suggests igneous dykes.

J. W. E.

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## III.—Geological Model of the Assynt Mountains.

THE North-West Highlands of Scotland from the time of Macculloch onwards have excited the attention of British geologists; now, thanks to their labours, and not least to those of Drs. Peach and Horne, the region stands as a type for the study of certain forms of earth-movement and mountain-building. The geology of this region has been fully described in the Survey memoir on *The Geological Structure of the North-West Highlands*: it is, however, a bulky volume, and the district itself is difficult of access; therefore, to help those who are unable to visit the ground to form a conception of the character and results of the great earth-movements, a model has been prepared of a selected portion. The model embraces an area of about 168 square miles, and is on a scale of 6 inches to 1 mile (vertical and horizontal); examples of it are exhibited in the Museum of Practical Geology, London, and in the Royal Scottish Museum, Edinburgh.

We have now before us a *Guide to the Geological Model of the Assynt Mountains*, by Drs. B. N. Peach & J. Horne, price 1*d*., which will be of the utmost assistance to students in arriving at an understanding of the model and of the great thrust-movements it exemplifies. Some of the place-names will be a little difficult for the southerner; after a struggle with Beinn nan Cnaimhseag or Cnoc na Glas Choille he may long for the military expedient of plain "Hill 60". The pamphlet is illustrated by a sketch-map and a number of sections which greatly assist in the interpretation of the geology. Within

thirty odd pages the authors have condensed, with admirable clarity, an immense amount of information; it will be difficult to find a more weighty geological pennyworth.

## IV.—Memoirs of the Geological Survey of Scotland.

The Geology of Mid-Strathspey and Strathdearn. Explanation of Sheet 74. By L. W. Hinxman, E. M. Anderson, and others. pp. 97. Edinburgh, 1915; published by Wyman & Sons, Ltd., London, E.C. Price 2*s.* 6*d.* net.

THIS is a continuation of the fine series of Survey memoirs on what is perhaps the most minutely mapped and described region of ancient rocks in the world. The area of 432 square miles dealt with lies almost wholly within the county of Inverness, and most of it is devoted entirely to sport. The country is mountainous and belongs mostly to the dissected plateau of the Highlands, of which the Monadhliath Mountains is a comparatively undissected portion, reaching 3,000 feet in height. To the south-east a part of the great 'monadnock' of the Cairngorm Mountains, with a mean elevation of 3,500 feet, rises out of the plateau surface. Three great river valleys, the Spey, Findhorn, and Nairn, cut across the plateau in a N.N.E. direction, of which the first two are certainly of pre-Devonian age.

The area is entirely underlain by the ancient metamorphic rocks of the Highlands and the igneous intrusions associated with them. Most of the metamorphic rocks belong to one or other of the main groups of the Moine Series, which are classified as pelitic schist and gneiss, siliceous schist and granulite, quartzite, limestone, and calc-silicate rock. These form the lower moorlands of the central and north-eastern parts of the area. Rocks which, owing to rapid alternations of lithological character, cannot be assigned to any of the above groups, and are classed as undifferentiated schists of the Moine Series, occupy the area around the southern granite masses, and form bands across the western and south-western parts of the region. A small area in the neighbourhood of Grantown is occupied by rocks which have a closer lithological affinity with those of the Central Highland or Banffshire Series, and are accordingly separated under the provisional name of the Grantown group. These various metamorphic rocks are fully described under their respective districts.

Igneous rocks which have been involved in the foliation are sparse, and are represented only by thin sills of epidiorite and hornblende schist. The three great granite masses of the Cairngorm Mountains, the Monadhliath Mountains, and Strathdearn belong to the Newer Granite period of intrusion (Old Red Sandstone), and are of post-foliation date. Two or three small bosses appear through the gravels of the Spey valley. The view that all these separate masses are continuous at varying depths beneath the roof of schist is supported by the petrographical identity of the several outcrops, the extensive granitization of the intervening areas of schist, and the behaviour of the outcrops in relation to the form of the ground. It is far more probable, however, that the mass is of batholithic habit, rather than that it is a "large branching laccolite . . . whose irregular upper surface

has been partially exposed, at different levels and often over wide areas, by denudation". A garnetiferous augite-diorite, remarkable for parallel intergrowths of garnet, felspar, and augite, forms an unusual variant of the Strathdearn granite. An interesting petrological chapter by Dr. J. S. Flett gives details of the igneous and metamorphic rocks, and describes kyanite-, sillimanite-, and staurolite-gneisses as products of the thermal metamorphism of the schists.

The region can boast of a magnificent range of glacial phenomena, equalling in clearness and beauty those of any other area in the British Isles. The Glacial Period is divided into four stages: the stage of maximum glaciation, in which there was a thick ice-sheet moving eastwardly; the stage of large confluent glaciers originating outside the area; a stage of separation of the confluent glaciers into independent valley glaciers; and finally a stage of high-level corrie glaciers. The retreat phenomena of the valley glaciers are finely displayed in a series of overflow and marginal channels, associated with lateral moraines, high-level marginal terraces, and flat spreads of sand and gravel that occupied the deeper embayments of the ice-margin. The six fine plates are all illustrative of various phases of the glaciation and physiography. Perhaps the best is the frontispiece, showing the great through-valley of the Lairig Ghru, cutting right through the summit plateau of the Cairngorm massif, and fronted by the fluvio-glacial plain of the Rothiemurchus Forest, which, unlike most Highland 'forests', appears to have some trees in it.

G. W. T.

## REPORTS AND PROCEEDINGS.

### I.—Geological Society of London.

1. *April* 14, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The President referred with regret to the death of the Rev. Alec Field, who was Assistant in the Society's Library and Office from 1900 until 1908. In the latter year he left the Society's service, in order to be trained as a missionary. He was among those lost on the s.s. *Falaba*, torpedoed by a German submarine on the afternoon of Palm Sunday, March 28, 1915. Mr. Field was returning to his post at Bida in Northern Nigeria.

The following communication was read:—

"Further Observations upon the Late Glacial, or Ponder's End, Stage of the Lea Valley." By Samuel Hazzledine Warren, F.G.S. With Notes on the Mollusca by Alfred Santer Kennard, F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.

The paper is supplementary to that previously published (Q.J.G.S., vol. lxviii, p. 213, 1912), and describes additional sections which increase the range of the deposits. They have now been traced, with the assistance that the author has received from Mr. A. Wrigley, for

a distance of 6½ miles along the valley and 2¼ miles across it. The section at Hedge Lane, Lower Edmonton, shows several thick, and for the most part undisturbed, Arctic plant-beds, which occur in a deep Drift-filled channel. The relative levels and stratigraphy point to the conclusion that the Hedge Lane deposits belong to a slightly earlier stage of the Low Terrace River Drift than the deposits of Ponder's End. Broadly speaking, they undoubtedly belong to the same group.

The author suggests that it would be a practical convenience if the East Anglian word 'platymore' were adopted for the underlying eroded floor of country rock beneath a later accumulation of Drift. The importance of this 'platymore' surface in the correlation of Drift deposits has been increasingly recognized during recent years, and it seems desirable that it should have a name.

The author supports the correctness of the view that the lower river-terraces are later than the higher river-terraces. Further evidence is also brought forward in support of his view that the Arctic deposits form an integral part of the Low Terrace Drift: that is to say, that they belong to the latest stages in the Pleistocene erosion of the valley, and are not remnants of earlier deposits.

One of the sections described appears to suggest that the climate became nearly as temperate as that of the present day before the mammoth and woolly rhinoceros became extinct.

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2. *April* 28, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The President announced the death, on April 16, of Richard Lydekker, who became a Fellow of the Society in 1883, and resigned only on December 16 last. He referred to the value of Mr. Lydekker's contributions to geology, and also to his services to the Society. Mr. Lydekker had been a Member of Council for fifteen years, and a Vice-President for four years.

The following communications were read:—

1. "A Composite Gneiss near Barna in the County of Galway." By Professor Grenville A. J. Cole, F.G.S., M.R.I.A., Director of the Geological Survey of Ireland.

The great mass of granite west of Galway town is seen on its northern margin to be intrusive in a metamorphosed series of Dalradian quartzites, limestones, and mica-schists, and has received a foliation which is parallel with the bedding of this series; this foliation is ascribed by the author to the partial absorption of sheets of the bedded series into its mass. Traces of similar intermingling occur in Town-parks (Galway town) and west of Barna. At Furbogh Bridge the granite contains pink crystals of orthoclase, at times 10 cm. long in the direction of the vertical axis, and these have become stranded, as it were, among the foliation planes of dark-green biotite-schist, into which they were carried by an intimate intermingling of the granite, with the schist into which it flowed. Quartz and smaller felspar-crystals from the granite abound in the resulting composite gneiss,

and the general effect is comparable with that of igneous intermixtures described from County Down and Skye. In the Galway instance, however, there is no sign of general fusion of the invaded rock, which retains its original foliation and controls the structure of the composite mass.

2. "Further Work on the Igneous Rocks associated with the Carboniferous Limestone of the Bristol District." By Sidney Hugh Reynolds, M.A., Sc.D., F.G.S., Professor of Geology in the University of Bristol.

The paper gives an account of the additional information, concerning the Carboniferous volcanic rocks of North Somerset, which has become available largely through digging trial-holes, since the publication in the Q.J.G.S. for 1904 (vol. lx) of a paper by Professor Lloyd Morgan and the author on the subject. The rocks occur at five localities: (1) Goblin Combe; (2) Uphill; (3) Limeridge Wood, Tickenham; (4) Spring Cove and Milton Hill, Weston-super-Mare; and (5) Woodspring or Middle Hope.

At Goblin Combe, as the result of digging nearly forty trial-holes, it was ascertained that the igneous rocks form two discontinuous, somewhat crescentic masses, each consisting of olivine-basalt overlain by a considerable thickness of calcareous tuff. At Uphill the evidence obtained was insufficient to determine whether the basalt is a sill or a lava-flow. At Limeridge Wood, Tickenham, where only debris of basalt had previously been recorded, the presence of an oval mass measuring about 60 by 25 yards was proved by digging trial-holes, and the fact that it is completely surrounded by limestone indicates its intrusive character. Several additional exposures are described on Milton Hill, where the lava forms a band about 150 feet thick. The lava at Middle Hope or Woodspring is shown to form an irregular and discontinuous mass.

Previous statements as to the essentially basaltic character of these rocks are confirmed. Olivine is present at each locality. Analyses, mainly made by Mr. E. G. Radley, show that in some of the rocks a high percentage of potash is present.

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3. *May* 12, 1915.—Dr. A. Smith Woodward, F.R.S., President, in the Chair.

The following communication was read:—

"On *Parka decipiens*, Fleming." By George Hickling, D.Sc., F.G.S., and Archibald W. R. Don, B.A., F.G.S.

The paper is a joint statement of originally independent investigations of this Old Red Sandstone organism. The views of Fleming, Hugh Miller, Mantell, Lyell, Powrie, Page, and others are quoted to illustrate the chequered career of this enigmatical fossil in geological literature. To Dawson and Penhallow, supported by Reid and MacNair, belongs the credit of making the first serious attempt to obtain definite evidence as to its nature and of establishing its vegetable character. The present account is based on the observation of great numbers of specimens in the field, and on the microscopic

study of impression-material, of thin sections, and of macerated material.

The plant is most abundant in the Lower Old Red of the Kincardine-Forfar-Perth area, where it is by far the commonest fossil, especially in the shale-bands; *Parka* is confined to the lower two-thirds of the Caledonian Series. It is recorded from a few other localities in Central Scotland, and also from the Upper Ludlow and Lower Old Red of the 'Hereford' area.

The organism is shown to be a complete cellular thalloid plant, agreeing generally in its vegetative structure with certain algæ, but differing from all known algæ in the production of cuticularized spores. The thallus is closely set with subcircular swellings ('discs'), each enclosing a mass of simple spores (homosporous). An investing layer, probably one cell thick, of relatively large cells surrounds the smaller-celled 'parenchyma' of the thallus. The spore-masses are individually enclosed by the latter tissue, but there is no indication of a specialized sporangial wall. The growth of the plant is marginal and indefinite, and mature spores are found in plants of all sizes—that is, so far as observed, in all plants that are in a suitable state of preservation. The structure described by previous writers as an 'indusium' is interpreted as the 'sole' of the thallus in a more or less detached condition. While the general structure and mode of growth of the plant make it very difficult to place it higher than the Thallophyta, it must be recognized that the organism is in some respects unique.

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## II.—Geological Society of Glasgow.

At a meeting on May 13, 1915, Professor J. W. Gregory read a paper by himself and Dr. Horne on "The Annan Red Sandstone Series of Dumfriesshire". He explained the different opinions that had been held at various times with regard to the age of the red rocks of South-Western Scotland. The identification of the age of these rocks and their allocation to their true stratigraphical position had been a matter of difficulty on account of the absence of fossils, with the exception of reptile footprints such as those of Corncockle Moor, and the fact that the rocks occurred in isolated areas. This had led to their all being classed simply as "New Red Sandstones", a loose and unsatisfactory term. It had been found that, in the absence of fossils, a study of the climatic and geographical conditions under which a sedimentary rock had been formed frequently gave useful guidance in identification, and this had proved to be the case in this instance. The rocks of the Annan district can be traced across the border and linked up with the St. Bees Sandstone, which is clearly of Lower Triassic age. The Lochmaben, Dumfries, etc., Sandstones agree rather with the Penrith Sandstone, which is Lower Permian, and exhibit an absence of the Red Shale and angular material which are so prominent in the Annan Series. The Annan Beds seem to have been laid down in lagoons traversed by strong currents, while those of Dumfries, etc., bear every mark of having been formed at a time when the country was covered by one continuous sheet of desert sand,

the small grains of pyrolusite and the type of false-bedding being quite characteristic of desert conditions. The only footprints got in the Annan Sandstones, also, are similar to those of the Trias, while those of the Dumfries Beds belong to Permian reptiles.

Mr. Peter Macnair read a paper on "The Hurlet Sequence in North Lanarkshire". He described the succession of strata in the East Kilbride, Carluke, and Strathaven districts, and pointed out that they could be correlated bed by bed with those of the Glasgow basin, with the possible exception of the Hurlet Limestone. He pointed out that the Hurlet Limestone was not so constant as was supposed, and that the Blackbyre ought really to be taken as the datum-line. His co-relation with adjacent areas depended upon the occurrence of the large form of *Productus giganteus* in the Blackbyre, the *Posidonomya corrugata* bed above the Hosie, and the Nielson shell bed above the Blackhall Limestone. He dealt particularly with the section seen at Thorntonhall, and said that he had recently found two Neilson shell beds there.

## III.—Zoological Society of London.

*March* 23, 1915.—R. H. Burne, Esq., M.A., Vice-President, in the Chair.

Mr. R. Lydekker, F.R.S., F.Z.S.,[1] presented a paper entitled "The True Coracoid", in which he stated that the element in birds and post-Triassic reptiles universally known as the coracoid is the homologue of the human coracoid process, and its equivalent the true coracoid of the monotremes and mammal-like reptiles.

## CORRESPONDENCE.

### CONCERNING 'LATERITE'.

Sir,—The discussion on laterite that arose from a letter of mine published some years[2] ago led to the appearance of a number of very interesting papers in the pages of this Magazine, the latest being Dr. Fermor's account of Professor Lacroix' work in French Guinea. My own views on laterite were, I think, made sufficiently clear in the discussion referred to, and I would not trouble you further were it not for a point connected with Dr. Fermor's last paper.

I have been engaged in the study of tropical weathering products for some time and find that one of the difficulties is *to prove*, when dealing with very fine-grained products, the presence of aluminium hydrates mixed with hydrous aluminium silicate. On p. 127 of the current volume of the Magazine Dr. Fermor mentions Mr. Edward's paper in *Economic Geology* (ix, pp. 112–21, 1914) on the occurrence of aluminium hydrates in clays, and after saying that the author examined a large series of *analyses of clays*, adds: "The percentage of bauxite thus detected in these clays." But no bauxite was detected. What Mr. Edwards did was to assume that even if

[1] This was the last paper communicated by the author, who died on April 16, 1915. See Obituary, Geological Magazine, May, p. 238.

[2] Dated July 4, 1909 (see Geol. Mag., 1909, p. 431).

a mixture of hydrous silicates of alumina were present in a clay, the resultant composition would be that of kaolinite, and to recalculate as bauxite from a number of analyses, with the help of a mineralogical slide-rule, the excess of alumina over that required for kaolinite. The objections to this procedure were so clear that I was surprised to read Professor Ries' detailed criticism in the June number of the same periodical.

Whatever one may think about laterite, whether the setting property is an essential characteristic or not, whether the word would exist but for that property or not, it is now clear that under the heading 'laterite' petrologists have taken up the study of hydrates of alumina as weathering products. I think the relationship is unfortunate, as may have been gathered previously, and that the main objection to Dr. Fermor's classification of laterites and clays (GEOL. MAG., 1911, p. 514), apart from the two new terms, is the necessity of long and difficult chemical analyses in place of determining the 'setting' property of laterite or plasticity of clay.

I need not dwell on the dangers of mineral recalculations in very fine-grained rocks where attempts at identification of component minerals only reach what a distinguished petrologist, under whom I once worked, called 'pious opinions', nor need I recall the dangers of assuming clays to be composed of kaolin. Mr. Hutchings' work in the 1894 volume of this Magazine will be remembered by most of those interested in the subject, and Professor Ries deals with the matter in his *Clays, their Occurrence, Properties, and Uses* (pp. 40 et seq.). In dealing with weathering products recalculation from a total analysis will not do, and the best method I have arrived at yet is fractional treatment with acids and alkali solution. The idea is simple. Alumina may be present in a weathering product as silicate or hydrate, or perhaps as colloid alumina, in a soluble form (kaolinite yields to prolonged acid treatment). If it is there as a silicate, gelatinous silica will be liberated and perhaps go partly into solution. Experiment with silica derived from powdered wollastonite by acid treatment shows that a rapid wash with hot 10 per cent K H O (say for 15 seconds) should take up all liberated silica without attacking other minerals in the rock to a serious extent. If no silica, or very little, is found in the K H O solution or the acid solution, then it is a fair presumption that the alumina dissolved was not there as a silicate or that there is only a slight admixture of silicate. Successive acid attacks should give approximately the amount of soluble hydrate (or colloid alumina) present. Will anyone tell me of a better method for mixtures of hydrous silicates and hydrates where only chemical analysis can be employed?

My impression so far is that aluminium hydrates are formed here in small quantities wherever aluminium silicates exist, and that kaolinite is decomposed to a certain extent. I have examined kaolinized felspar crystals in this connexion, the kaolin being a product of weathering, and believe them to contain some hydrate. One chemist confirms my results. Another contradicts them.

A point of some interest to me has cropped up lately in connexion with the discussion about laterite in this Magazine. Dr. Evans said